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MASSACHUSETTS AGRICULTURAL COLLEGE

THIRTY-FOURTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PARTS I AND II

1921

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approved by the
Supervisor of Administration.

THIRTY-FOURTH ANNUAL REPORT

OF THE

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PART I

REPORT OF THE DIRECTOR AND OTHER OFFICERS

PART II

DETAILED REPORT OF THE EXPERIMENT STATION

BEING PARTS III AND IV OF THE FIFTY-NINTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL COLLEGE

A RECORD OF THE THIRTY-NINTH YEAR FROM THE FOUNDING OF THE STATE AGRICULTURAL EXPERIMENT STATION

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Massachusetts Agricultural Experiment Station.

OFFICERS AND STAFF.

STATION STAFF.

Administration.

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JOSEPH B. LINDSEY, Ph.D., *Vice-Director*.
FRED C. KENNEY, *Treasurer*.
HENRY S. GREEN, A.B., LL.D., *Librarian*.
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MISS F. ETHEL FELTON, A.B., *Clerk and Editorial Assistant*.

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ALEXANDER E. CANCE, Ph.D., *Professor*.
MISS LORIAN P. JEFFERSON, M.A., *Assistant Research Professor*.

Agriculture.

EDWIN F. GASKILL, B.Sc., *Assistant Research Professor*.
ROBERT L. COFFIN, *Investigator*.

Botany.

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PAUL J. ANDERSON, Ph.D., *Professor*.
ORTON L. CLARK, B.Sc., *Assistant Professor*.
WEBSTER S. KROUT, M.A., *Assistant Research Professor*.
MISS ANNA M. WALLACE, M.A., *Curator*.
MISS GLADYS I. MINER, *Stenographer*.
ALYN S. BALL, *Laboratory Assistant*.

Cranberry Station.

HENRY J. FRANKLIN, Ph.D., *Research Professor in Charge*.

Entomology.

HENRY T. FERNALD, Ph.D., *Professor*.
ARTHUR I. BOURNE, A.B., *Assistant Research Professor*.
HARLAN N. WORTHLEY, B.Sc., *Investigator*.
MISS BRIDIE E. O'DONNELL, *Stenographer*.

Horticultural Manufactures.

WALTER W. CHENOWETH, M.Sc., *Professor*.

Market Gardening and Market-Garden Field Station.

HAROLD F. TOMPSON, B.Sc., *In Charge, Market-Garden Field Station*.

Meteorology.	JOHN E. OSTRANDER, A.M., C.E., *Meteorologist.*
Microbiology.	CHARLES E. MARSHALL, Ph.D., *Professor.* ARAO ITANO, Ph.D., *Assistant Professor.*
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Pomology.	FRED C. SEARS, M.Sc., *Professor.* JACOB K. SHAW, Ph.D., *Research Professor.* ARTHUR P. FRENCH, B.Sc., *Investigator.* Miss ETHELYN STREETER, *Stenographer.*
Poultry Husbandry.	JOHN C. GRAHAM, B.Sc., *Professor.* HUBERT D. GOODALE, Ph.D., *Research Professor.* Miss RUBY SANBORN, A.B., *Clerk.* Miss DORIS TOWER, *Stenographer.*
Veterinary Science.	JAMES B. PAIGE, B.Sc., D.V.S., *Professor.*[1] G. EDWARD GAGE, Ph.D., *Professor of Animal Pathology, Acting Head of Department.* JOHN B. LENTZ, V.M.D., *Assistant Research Professor.*

CONTROL SERVICE.

Miss ETHEL M. BRADLEY, B.Sc., *Analyst, Feed Control.*
RAY A. CARTER, *Collector of Blood Samples, Poultry Disease Elimination.*
OLIVER S. FLINT, B.Sc., *Analyst, Poultry Disease Elimination.*
HENRI D. HASKINS, B.Sc., *Official Chemist, Fertilizer Control.*
JAMES T. HOWARD, *Inspector, Feed and Fertilizer Control.*
ANN SMITH, *Analyst, Poultry Disease Elimination.*
PHILIP H. SMITH, M.Sc., *Official Chemist, Feed Control.*
RAYMOND W. SWIFT, B.Sc., *Analyst, Fertilizer Control.*
LEWELL S. WALKER, B.Sc., *Assistant Official Chemist, Fertilizer Control.*
Miss CORA B. GROVER, *Stenographer, Control Service.*

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[1] On leave. [2] Temporary appointment.

REPORT OF THE DIRECTOR.

SIDNEY B. HASKELL.

REVIEW OF THE YEAR.

The year just past has seen the completion of reorganization of station work on a project basis. There have been a number of difficulties in attaining this end, among them being the fact of many long-continued pieces of work, started in some cases nearly thirty years ago, which were not adapted to present methods of project organization. Through committee service, however, all such projects have now been subjected to strict analysis. Some of the older projects have been reorganized; others have been brought to completion and await only suitable time for publication. In making report on the present project organization of the station, it seems best to ignore departmental organization save in a minor way, and to classify on the basis of service expected of the projects.

Utilization of Station Work.

A most encouraging development of the year has been the increased utilization of station work in several lines of agricultural endeavor. As concrete illustration, the organization by the Massachusetts Fruit Growers' Association of a nursery certification plan, whereby damage and loss arising from the old difficulty of orchard stock being found untrue to name may be obviated, is a direct result of an investigation started some eight years ago by Dr. Shaw of the Department of Pomology. The work of the Department of Botany has likewise found immediate application in at least two different directions, — first, in giving to the tobacco growers of the Connecticut valley a method whereby "tobacco wildfire," a disease comparatively new in this section, may be controlled by spraying of the seed-bed; and secondly, the demonstration, through the excellent work done in the eastern part of the State, in co-operation with the Nashoba Fruit Growers' Association and several of the county farm bureaus, that the apple scab, a disease which caused very serious financial loss in 1920, can be controlled. The bringing together in bulletin form of available information on the composition, nature and properties of insecticides and fungicides, through the Departments of Chemistry, Entomology and Botany, is a service to fruit growers and general farmers for which they seem to be most appreciative. The work done in the Department of Plant and Animal Chemistry in studying the possibility of successful preservation of apple pomace promises to bring into general use a home-produced by-product of manufacturing which has heretofore been largely wasted. The work done in the same department and in the Department of Agriculture, extending back for a period of years, on the effectiveness of ammonium sulfate is also very timely, in view of the greatly increased national production of this commodity. Space will not permit of more detailed illustrations.

Changes in Staff.

There have been six resignations during the year; one partial transfer of a station worker to the teaching department of the institution; one staff officer retired through the automatic provisions of the retirement law; and four appointments to new positions. In detail these changes are as follows: —

Miss Anne C. Messer, investigator in chemistry, resigned Jan. 31, 1921, on account of ill health, after a little more than a year of efficient service. The position has been filled by the appointment of Mr. Charles O. Dunbar, a recent graduate of the College.

Miss Rebecca L. Mellor, clerk in the Department of Plant and Animal Chemistry, resigned July 13, 1921. Miss Mellor had given very satisfactory service for a period of seven and one-half years. Miss Margaret Eppler has been appointed in her place.

Miss Marguerite G. Ickis, curator in botany, resigned her position July 31, 1921. Among other items of service to the station and institution particularly noteworthy is the excellence of her photographic work on difficult subjects. This work has added value to the publications of her department, and will continue to add value as her work is published in years to come. Miss Anna M. Wallace of Smith College has been appointed curator.

Mr. Charles R. Green resigned as station librarian in August. For thirteen years Mr. Green has served in the dual position of librarian for the College and for the Experiment Station. His zeal in the building up of a real scientific library was unflagging. His never-failing courtesy in helping our men to obtain literature on various subjects made his services greatly appreciated and his loss to the station staff all the more keenly felt. Dr. Henry S. Green has been appointed librarian.

On Aug. 10, 1921, Dr. George H. Chapman, who had been in the service of the institution since 1907, resigned his position as research professor of botany to take up research work with the newly organized Connecticut Valley Tobacco Improvement Association. Dr. Chapman's loss is much to be regretted. He has had wide experience in his subject-matter, and particularly as a specialist on certain problems connected with the production of tobacco. He had several times visited the tobacco sections of Porto Rico as expert in the employ of large tobacco companies, and in this and other ways had fitted himself to render expert service to this relatively important Massachusetts industry. Despite the loss to the institution incurred by his resignation, it is gratifying to know that Dr. Chapman will continue in research work, although under different auspices. The position has not been filled.

Under date of Jan. 21, 1921, Mr. C. L. Beals, assistant research professor of chemistry, asked for a year's leave of absence without pay, in order to enter upon research work in preservation of milk by-products for the Sheffield Farms Company of Hobart, New York. Toward the end of the year Mr. Beals signified his intention of resigning, thus withdrawing permanently from the work of the station. It is with regret that we have felt obliged to recommend that the resignation be accepted, for Mr. Beals had shown great promise as an investigator. Here again, however, the apprenticeship served by Mr. Beals in the station has fitted him for an important research position, — a position in which success will ultimately react to the benefit of dairy farmers the country over. The position has been filled by Mr. John G. Archibald, a graduate of the Agricultural College at Guelph, Ontario.

As of June 1, 1921, Dr. J. B. Lentz was transferred from full time in Experiment Station service to half-time instructional work and half-time station work. This transfer was made necessary by the illness of Dr. James B. Paige, head of the Department of Veterinary Science.

On November 20 Dr. William P. Brooks, formerly director of the Experiment Station, and for nearly thirty years agriculturist of the station, but more recently consulting agriculturist, was placed on full retirement by the State Board of Retirement, having reached the age of seventy years. Dr. Brooks was best known because of the technical and scientific work done during the time over which he was agriculturist of the station. He imported to this country the first trial lot of Japanese millet, a crop which has made a place for itself on nearly all dairy farms in the northeastern part of the country. He also was instrumental in importation and early trials of the Japanese soy bean, a crop which has become important in many sections, but which, as it happens, has not yet established itself in the North. Dr. Brooks also was an acknowledged expert on fertilizer use, and during his many years with the station developed this branch of the work to a very great degree. It is with gratification that we report that, despite automatic retirement under the above-mentioned law, his services will still be available to the station in a consulting capacity.

Mr. Arthur P. French of Ohio State University was appointed investigator in pomology and began work in July.

The poultry disease elimination work was reorganized in September, with the following appointments: Oliver S. Flint, specialist in charge; Miss Ann Smith, laboratory assistant; and Ray A. Carter, collector of blood samples.

Changes in Equipment Organization.

During the year the Harlow farm, so called, was added to the land equipment of the Experiment Station. This area has been under the supervision of the Department of Pomology, and the transfer represents nothing more than an attempt to maintain existing educational values on this tract and add to them certain research values. The total area is in the neighborhood of thirty acres, about one-half of which is already planted and brought under definitely organized projects. The remaining area must be underdrained before it can be effectively used. A project for this purpose has already been submitted. Once this is done, the land so improved will be available for experiments with small fruits, blueberries, and possibly other native fruits.

In the summer of 1920 definite decision was reached to the effect that the Tillson farm should be developed as an experimental poultry farm. Projects were submitted for the equipment of this farm so as to admit of permanent housing of station flocks, and to avoid the danger of disease contamination which comes from housing them on a part of the institutional grounds frequently visited by poultrymen from all over the State. Since money was not appropriated for this purpose, the Department of Poultry Husbandry is still laboring under a severe handicap. Some progress has been made, however, in the development of the farm for the purpose in question. The rough pasture land not suited for tillage purposes is being developed for range purposes, the other area utilized for the time being in several pieces of miscellaneous experimental work.

Publications of the Year.

Annual Report.

Thirty-third annual report:

Part I. Report of the Director and Other Officers; 60 pages.

Part II. Detailed Report of the Experiment Station; 136 pages (Bulletins Nos. 195–200).

Combined Contents and Index, Parts I and II; 16 pages.

Bulletins.

No. 201. Insecticides and Fungicides for Farm and Orchard Crops in Massachusetts, by E. B. Holland, A. I. Bourne and P. J. Anderson; 38 pages.

No. 202. Rust of Antirrhinum, by William L. Doran; 28 pages.

No. 203. Tobacco Wildfire: Preliminary Report of Investigations, by G. H. Chapman and P. J. Anderson; 16 pages.

No. 204. Thirty Years' Experience with Sulfate of Ammonia, by F. W. Morse; 16 pages.

No. 205. The Nutritive Value of Cattle Feeds. 3. Dried Apple Pomace for Farm Stock, by J. B. Lindsey, C. L. Beals and J. G. Archibald; 14 pages.

No. 206. Eighth Report of the Cranberry Station, by H. J. Franklin; 20 pages.

Bulletins, Technical Series.

No. 4. Development and Pathogenesis of the Onion Smut Fungus, by P. J. Anderson; 36 pages.

Bulletins, Popular Edition.

No. 201. Insecticides and Fungicides for Farm and Orchard Crops in Massachusetts, by E. B. Holland, A. I. Bourne and P. J. Anderson; 16 pages.

Bulletins, Control Series.

No. 15. Inspection of Commercial Feedstuffs, by Philip H. Smith and Ethel M. Bradley; 34 pages.

No. 16. Inspection of Commercial Fertilizers, by H. D. Haskins, L. S. Walker and R. W. Swift; 40 pages.

No. 17. Inspection of Lime Products Used in Agriculture, by H. D. Haskins, L. S. Walker and R. W. Swift; 8 pages.

Meteorological Reports.

Nos. 385–396, inclusive, 4 pages each.

REPORT ON PROJECTS.

Plant Nutrition.

Chemical Investigations.

Department of Plant and Animal Chemistry.

Project 6. "Lime absorption and acidity of Field A."

Professor Morse and Assistant Professor Jones.

This study of the application of fundamental laws affecting solubility in the soil solution has led to important results which are now being prepared for publication. Following this it is expected that a chemical study will be made of the reaction between nitrate of soda, muriate of potash and lime as manifested by the composition of the drainage water.

Project 7. "Effect of sulfate and muriate of potash on the soils of Fields A and B."

Professor Morse and Assistant Professor Jones.

Work on this project is being carried on in connection with that of the one immediately preceding.

Project 14. "A study of the availability of soil potash, with the object of developing a system of diagnosis for soils of the State."

Professor Morse and Assistant Professor Jones.

This work supplements that carried on some years back by former Director Brooks in the investigation of subsoil potash, and during this past year was confined to an attempt at measuring the effect of moisture on the availability of soil potash.

Microbiological Investigations.

Department of Microbiology.

Project 2. "Soil fertility as influenced by micro-organisms in their relation to the presence and disappearance of organic matter."

Assistant Professor Itano and Mr. Sanborn.

Particular attention has been given to the activities of *Azotobacter* and *Bacillus radicicola* in their relation to those organic matters which are known as "growth accessory substances." An electrometric method for the determination of carbon dioxide, which was developed last year, has been employed in the investigation. The results of the investigation, together with the method used, will be ready for publication in the near future. There has also been a study made of the microbial decomposition of cellulose.

Physiological Investigations.

Department of Botany.

Project 1. "Optimum conditions of light for plant response."

Assistant Professor Clark.

This project was started in 1915 under the Adams fund. At present the work is divided into two parts: "A study of the light requirements of field and garden crops," and "Study of the effect of ultra-violet light on plant growth." The investigation is carried on both in the greenhouse and out of doors, and by natural as well as by artificial light.

Project 15. "Plant stimulation by formaldehyde."

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Owing to Dr. Chapman's resignation from the station staff, no work has as yet been done on this project.

Department of Pomology.

Project 1. "Study of the interrelation of stock and scion in apples."

Professor Shaw.

This project was begun in 1912, and the main orchard set in 1915 and 1916. A new orchard of 450 trees was set in the spring of 1921 from the surplus trees on known roots in the nurseries, in which it is planned to investigate the nature of the graft union between certain varieties. In resetting these trees the relation of crown gall to different varieties was studied and data collected showing that each root variety exhibits a special form of the gall, and that some varieties are highly resistant to the disease. No reports on this project have as yet been published.

Project 12. "Apple variety fruit spur study."
Professor Shaw and Assistant Professor Drain.

This project comprises a detailed study of individual fruit spurs, in an endeavor to define the service and functions of pruning and fertilizing in modifying fruit-bud formation and fruit production. The field work is checked by chemical study of the elaboration of food in the fruit spur, and by micro-chemical tests.

Project 14. "Winter injury of brambles."
Professor Shaw, Professor Morse and Assistant Professor Clark.

This project, co-operative between the Departments of Botany, Chemistry and Pomology, was organized to investigate the cause of the winterkilling of brambles as apparently brought about by differential fertilization with potash salts. This winterkilling was observed again and again on some of the plot work initiated by Dr. Goessmann years back, but was never satisfactorily explained. In an attempt to solve this problem both chemical and physiological tools are being used.

Soil Management and Fertilizer Tests.

Department of Agriculture.

Project 1. "Comparison of nitrogenous fertilizers."
Professor Morse and Assistant Professor Gaskill.

This investigation is co-operative with the Department of Plant and Animal Chemistry. While the experiment was originally instituted to study the relative value of different sources of fertilizer nitrogen, the greatest contributions have been incidental to what was considered the main objective. The possibility of maintaining yields almost indefinitely without the use of fertilizer nitrogen has been demonstrated. Certain problems of soil acidity have been studied, and the presence in acid soils of certain toxic substances experimentally proved. The latest contribution from this field was in the publication of Bulletin No. 204, entitled "Thirty Years' Experience with Sulfate of Ammonia."

Project 3. "Residual value of excess phosphate applications."

Assistant Professor GASKILL.

In this project attempt is being made to utilize reserves of phosphoric acid built up in the soil from past fertilizer treatment. One of the older station plots, having an unbroken history of twenty-five years, is now being used for this work. The experiment as changed is now in its second year, and hence has not given definite results.

Project 4. "Methods of applying lime, and quantity of application."

Assistant Professor GASKILL.

In preparing land for future alfalfa crops, lime has been applied in varying rates, plowed under, harrowed into the surface, and both plowed under and harrowed in. The plots are repeated in quintuplicate.

Project 6. "Top-dressing permanent grasslands."

Assistant Professor GASKILL.

Certain areas of land formerly used for experimental work, but which were in old sod at the beginning of the experiment, are being used in this test. The fertilizer applications are purposely kept at a low rate. The results of the first year, as might have been expected, emphasize the great importance of nitrogen in producing heavy yields of grasses.

Project 7. "An attempt to restore productive fertility to worn-out and maltreated soils."

Assistant Professor GASKILL.

This project was initiated in the spring of 1921. The plots of the old South Soil Test, which had received differential fertility treatment for over thirty years, and in some cases reached a very low state of productiveness, furnish the basis for the study. The results the first year indicate an astonishingly rapid and marked response to present rational treatments.

Department of Botany.

Project 13. "Ecological study of pasture vegetation."
Professor OSMUN and Director HASKELL.

This project is co-operative with the Department of Agriculture. Its primary object is to determine the effect of chemical fertilizers and lime on natural pasture vegetation, in the hope of making some contribution toward solving the problem of bringing run-down pastures to a state of productivity. In the pasture on the Tillson farm a number of plots of equal area were selected, each dominated by a different type of vegetation characteristic of run-down pastures. These were designated as "moss area," "cinquefoil area," etc., according to the principal plant growths which they embraced. The attempt is being made to determine the specific effect on each dominating type of vegetation of treatment given, and likewise the possibility of enabling clover and the grasses to successfully compete with these types of natural vegetation.

Market-Garden Field Station.

Project 1. "Manure economy tests."
Professor TOMPSON.

Work under this project was started in 1918, in an attempt to solve the serious fertility problems developed through increasing shortage of animal manures. Results to date indicate that the amount of manure as used by market gardeners may be greatly reduced in case the manure is supplemented with chemical fertilizers.

Project 5. "Growth control by means of intercropping."
Professor TOMPSON.

Work under this project represents an attempt to use cover crops, intersown, in controlling the growth of certain vegetables in the same way that cover crops as used in the orchard are supposed to control tree growth. The fertilizer schedule in this work is so arranged as to produce rapid and luxuriant growth during the first part of the season, it being expected that the intercrop will relieve the soil of any surplus as the ripening period approaches. This project was started in the spring of 1921.

Department of Pomology.

Project 5. "Comparison of cultivation and sod mulch in a bearing orchard."

Professor SHAW and Mr. FRENCH.

This project was started in the spring of 1921 on a ten-year-old orchard of Baldwin, McIntosh, Wealthy and Oldenburg, on the Harlow farm. The area is about three acres and is divided into seven plots, three of which are to be seeded to Kentucky blue grass and to receive 300 pounds of nitrate of soda per acre. The other four plots are to be cultivated with a cover crop and are to receive little or no fertilizer.

Project 6. "Comparison of clover and grass in a sod mulch orchard."

Professor SHAW and Mr. FRENCH.

The trees on the area assigned to this project were planted in 1911 and consist of Wagener, Wealthy and Oldenburg. Two of the five plots were seeded to grass in the spring of 1921, and are to receive a complete fertilizer designed to further grass production. On the other three plots the fertilizer application is confined to phosphorus and potassium, with a mixture of white clover and Kentucky blue grass sown. It is hoped by this differential treatment to foster the growth of clovers, and thus make measurement of the effect of grass and applied nitrogen as against the effect on the apple trees of clover plus such nitrogen as it may accumulate from the air. The first effect, as might have been expected, was more marked on the two plots receiving nitrogen.

Project 7. "Test of fertilizers in a sod mulch orchard."

Professor SHAW and Mr. FRENCH.

This orchard was brought under experiment in the spring of 1921, and in area is about two and one-fifth acres. The fertilizer treatments include the following: —

300 pounds nitrate of soda per acre annually.

300 pounds nitrate of soda
300 pounds acid phosphate } per acre annually.

300 pounds nitrate of soda
300 pounds acid phosphate
200 pounds sulfate of potash } per acre annually.

The whole orchard was plowed and harrowed repeatedly last spring in preparation for starting the experiment, which probably accounts for the fact that while fertilizers had a definite effect on the cover crop, none could be observed on the trees themselves.

Project 8. "Test of cover crops for apple orchards."
Professor Shaw and Mr. French.

The crops used have been red clover, buckwheat, timothy, redtop, weeds, and rape, although the latter crop made but a poor stand. Individual tree records are being taken. No report on this project has as yet been made, and probably none can be made in the near future.

Project 15. "Orchard fertilization."
Professor Shaw and Assistant Professor Gaskill.

This orchard was assigned to the Department of Pomology in the spring of 1921. Previously it has been carried on as an agricultural project, with reports made at more or less frequent intervals in the annual reports of the Experiment Station, the last of these reports being in 1914. All records of this orchard have been summarized, and are now nearly ready for publication. The plan of fertilization was changed this last spring to one supplying approximately equal amounts of nitrogen and phosphoric acid to all the fertilized plots, but carrying on the differential potash treatment as formerly.

Project 16. "Test of different amounts of nitrate of soda."
Professor Shaw and Assistant Professor Drain.

This investigation was started in the spring of 1921, utilizing certain areas in the College orchard. Nitrate of soda is applied at the rate of 5, 10 and 15 pounds per tree. Since the effect of the nitrate on fruit production is secured in part through its effect on wood production, it will be several years before the results will be worthy of record.

Crop and Crop Management Studies.

Plant Introduction.

Cranberry Station.

Project 5. "Blueberry investigations."

Professor Franklin.

This project was commenced in 1915, and is co-operative with the Bureau of Plant Industry of the United States Department of Agriculture. About half an acre of sandy soil, underlain with considerable peat, is now planted to this crop. The work includes a test of selected *versus* unselected bushes, as transplanted from adjacent woodlands and swamps; trial of new varieties as produced through the efforts of Mr. Frederick Coville of the United States Department of Agriculture; propagation work; and observation on disease and insect control.

Department of Pomology.

Project 17. "A study of the cultivation of the high bush cranberry."

Professor Shaw.

Two hundred plants of Viburnum were received in the spring of 1921 from the United States Department of Agriculture and set out on the Tuxbury land. These plants are in part seedlings, and in part propagated from cuttings from superior plants.

Strain and Variety Tests.

Department of Agriculture.

Project 5. "Test of meadow fescue *versus* timothy under varying drainage conditions."

Assistant Professor Gaskill and Mr. Coffin.

Work on this project was started in the summer of 1921, with two fairly well-defined moisture conditions in the field, and plots repeated in quadruplicate.

Market-Garden Field Station.

Project 4. "Variety and strain test of tomatoes."
Professor TOMPSON.

Twenty-five different strains and varieties were under test during the season of 1921, eighteen of these in quadruplicate plots, the balance in simple duplicates. A part of this work was repeated at the home station at Amherst, so as to reduce error due to environment. The most striking indication of the year's work is that differences in yield due to soil conditions are apparently paramount over many of the differences supposedly inherent in the seed itself, and due either to breeding or to the climatic environment in which the seed is produced.

Department of Pomology.

Project 2. "A study of tree characters of fruit varieties."
Professor SHAW and Mr. FRENCH.

This project was started in 1912 for the purpose of getting information which would make possible the identification of varieties in the nursery, and which would also serve as a basis for the comparative studies to be made in connection with Project 1, "Study of interrelation of stock and scion in apples." The first report was published in 1914 as Bulletin No. 159, under the title, "The Technical Description of Apples." Photographs of about 100 varieties have been made, and a bulletin discussing the identification of varieties by their leaves is in preparation. So promising has been the progress made that a phase of the work has been taken over by the Massachusetts Fruit Growers' Association, and a plan developed for the certification of certain varieties of apple trees when grown in the nursery row. In the first work done under this plan, 267 out of a total of 2,847 trees were found to be untrue to name, and hence were refused certification. Four hundred and thirty-eight younger trees propagated from trees found untrue to name were also found, making a grand total of 705 trees thus prevented from coming into the hands of practical fruit growers under incorrect names.

To supplement the leaf study work as completed, it is planned to make a study of the winter characters of the bark, wood and buds of apple varieties, in the expectation that these characters may be of further assistance in variety identification, and may render possible the identification of varieties during the dormant season.

Project 13. "Study of varieties of tree fruits."

Professor Shaw and Assistant Professor Gould.

This is an attempt to collect valuable data by keeping individual tree records of a number of different varieties in the College orchard. It is expected that it will be possible to correlate the performance of different varieties with certain of their growth characters.

Breeding.

Market-Garden Field Station.

Project 6. "Improvement of Martha Washington asparagus."

Professor Tompson.

The yield records in 1,062 individual plants were taken during the season, all of these being of the same strain and supposedly representing a pure line. Wide differences were noted in behavior. A number of plants gave less than five marketable stalks each, while the best plant gave forty-four. Thirty-eight of these forty-four stalks were over half an inch in diameter, which indicates good quality as well as high yield. Another plant gave a crop of seventeen stalks, of which eleven were over one inch in diameter. This study is preliminary to a definite attempt at improvement.

Department of Pomology.

Project 3. "The genetic composition of peaches."

Professor Shaw.

Owing to weather conditions in the spring of 1921, there was no fruit on the breeding orchard this past season. It is impossible, therefore, to make a report of progress at this time.

MANAGEMENT.

Department of Pomology.

Project 4. "Experiments in pruning apples."

Professor SHAW.

These experiments were started in 1916, and compare the following methods of pruning apple trees: globular or vase head, modified leader head, a new form of the true leader head, and unpruned head. Results to date confirm the growing belief that pruning is a dwarfing process, and that heading back is detrimental to fruit-bud formation.

Project 9. "Testing methods of pruning."

Project 10. "Testing of pruning methods on Northern Spy and other varieties."

Professor SHAW.

These are similar to the above in scope. Project 9 is carried out in connection with Project 8, "Test of cover crops for apple orchards."

Crop Protection.

INSECT ENEMIES OF VEGETATION.

Department of Entomology.

Project 2. "Economic importance of digger wasps."

Professor FERNALD.

This project was started in 1909, and represents an attempt to establish the economic importance of the digger wasps and to determine the number and kinds of insects which may be parasitized by them. This project is nearing completion.

Project 3. "Control of the onion maggot."

Assistant Professor BOURNE.

Work on this project has progressed to the point where the possibility of poisoning the onion maggot fly before completion of oviposition has been established. Owing to the seasonal nature of the onion maggot attacks, and to the difficulty of getting comparable results on areas widely separated, it has not yet been possible to organize field test work on an effective scale.

Project 4. "Control of squash vine borer."

Mr. Worthley.

The work of the past year has developed tentative methods for the control of this insect. Such methods are now to be tried out on a field scale.

Project 5. "Control of the squash bug."

Mr. Worthley.

Up to date, results have been negative, in that some of the control measures usually advised have been shown to be worthless under the conditions tried. Positive results have not been secured.

Project 6. "Control of insects in a candy factory."

Professor Fernald and Mr. Worthley.

This work was initiated at the urgent request of a Massachusetts manufacturer who found his product badly infested with certain insects. The problem was that of fumigating to destroy the insect without at the same time injuring the product of the factory. Work is completed and results written up, but not prepared for publication.

Project 7. "Studies of insect outbreaks in various localities."

Professor Fernald.

This project was started a number of years ago, and has been continued through the making of observations year by year. Work this last year was confined to observations on the presence and development of the corn ear worm and seed corn maggot.

Project 8. "Pest limits in Massachusetts."

Professor Fernald.

This project attempts to correlate the presence and development of certain insect pests with geographical and climatic conditions in the various parts of the State. Of necessity, observations must be continued over a long period of years before the results will have authoritative value.

Project 9. "Number of generations of codling moth in Massachusetts as related to advisability of spraying for the second generation."

Assistant Professor Bourne.

This project consists of observations on the development of second generation codling moths in the different climatic areas of Massachusetts.

Project 10. "Hatching dates for scale insects."

Assistant Professor Bourne.

This project takes in all of the more important scale insects, and attempts to determine hatching dates as affected by seasonal developments. It is hoped that a service of the project may be the establishment of dates on which spraying for certain of these scale insects may be effectively practiced.

Cranberry Station.

Project 1. "Injurious and beneficial insects affecting the cranberry."

Professor Franklin.

Dusting with lead arsenate as a control for gypsy-moth worms in their early stages was tried on two bogs with satisfactory results. The green spanworm was more prevalent than for many years, destroying the promise of a fine crop on two areas of fifty and twenty-five acres in Rochester, and on an area of two or three acres in Carver. Life history studies on this insect were continued. The brown spanworm practically disappeared as a cranberry pest this past year. The fruit worm was more destructive than for several years. Its hatching date was later than usual. Extensive examinations and counts proved that the common parasite was abundant. Wetting of the cocoons with a solution of sodium cyanide was tried as a possible new method of control.

Plant Disease Control.

Department of Botany.

Project 2. "Tobacco investigations and a study of so-called tobacco sick soils."

Professor Chapman and Professor Anderson.

Active work on this project was started through a field survey in the summer of 1916. The year following, fertilizer plots were located on three tobacco farms in the Connecticut valley. With some necessary changes these plots were continued over four years, when the experience gained made it apparent that further progress could be made only on land under the complete control of the station. Experimental work on privately owned land was therefore discontinued, being replaced by experimental work carried on at the Tillson farm. The reorganized project embraces a study of soil reaction as a means of controlling root rots of tobacco; also a study of the effects of soil reaction on the growth and development of the crop.

Project 3. "Investigations of the methods of controlling lettuce drop."

Professor Osmun and Assistant Professor Krout.

Although this project was not formally organized until January, 1918, the department had previously conducted many investigations along this line. During the year just past, a paper dealing with the more technical phases of this work was submitted for publication in the Journal of Agricultural Research. The most striking result of the investigation to date is the determination of the fact that lettuce drop may be easily and inexpensively controlled by treating infected soils with a formaldehyde solution. A complete report of the work in bulletin form is in course of preparation.

Project 5. "Experimental spraying for the control of cucumber mildew under glass."

Assistant Professor Krout.

Because but two serious epidemics of this disease have occurred since the project was started, actual spraying tests have been conducted two seasons only. During the summer just past greenhouse cucumbers were heavily attacked, with losses ranging from 25 to 60 per cent. The use of 4–6–50 Bordeaux mixture appears to be profitable, even though anything approaching perfect control seems at present unattainable.

Project 6. "Investigation of onion diseases."
Professor OSMUN and Professor ANDERSON.

Work under this project has to date been focussed on onion smut, the most destructive disease of onions in this State. A technical paper, entitled "Development and Pathogenesis of the Onion Smut Fungus," is now in press, to be published as a station bulletin. Very striking results have been obtained through formaldehyde treatment of infected soils. The chief difficulty in the application of this method appears to be mechanical limitations in machinery used for distribution of the formaldehyde.

Project 9. "Investigation of carrot blight."
Assistant Professor KROUT.

The causal organism of this disease has been isolated and studied under culture, work has been done on seed disinfection, and field plots have been sprayed. The work, however, has not progressed far enough to warrant definite conclusions.

Project 10. "Apple disease control investigations."
Assistant Professor KROUT.

This project was presented in February of 1921, in response to an urgent appeal of apple growers in the eastern part of the State for help in controlling apple scab and black rot. Through the co-operation of the Nashoba Fruit Producers' Association and several of the county farm bureaus, transportation facilities, spraying equipment, labor and orchard space were allowed the station for carrying on this work. The value of the season's results was somewhat reduced by late spring frosts which killed a large part of the fruit buds. Indications to date are that proper spraying can control scab in eastern Massachusetts. The best results were obtained on plots where Bordeaux mixture was used for the "pink bud" spray, and liquid lime-sulfur for later applications. Results from dusting were inconclusive. This work should continue at least three years and probably longer.

Project 14. "Investigation on control of tobacco wildfire."
Professor Chapman and Professor Anderson.

This project was organized in May, 1921, in response to an emergency brought about by the sudden and general appearance of tobacco wildfire in the seed-beds of the Connecticut valley. Previous reports of its appearance had been limited to field outbreaks at several points in 1919 and 1920. Because of the great importance of this crop in the Connecticut valley, projects of seemingly lesser importance were laid aside in order to meet the emergency. A preliminary report on investigations was published in the fall as station Bulletin No. 203. Work in greenhouse and laboratory was conducted throughout the winter, and will be carried to seed-beds and plots this coming season.

Cranberry Station.

Project 2. "Cranberry disease work."
Professor Franklin.

This project was conducted, as heretofore, in co-operation with the Bureau of Plant Industry of the United States Department of Agriculture. Additional observations were made on the distribution of the "false blossom" disease. Extensive cultural work was done to determine the periods of greatest infection from different putrefactive fungi, and to discover the effect of June flooding on infection. Further tests and observations on the effect of reflooding on the "rose bloom" disease were made. Spraying tests with lead arsenate as a cranberry fungicide were continued extensively.

Spray Materials — Their Nature and Use.

Department of Botany.

Project 12. "Tests of fungicides on potatoes."
Professor Osmun and Professor Anderson.

This work was planned to test the value of various types of commercial fungicides used for spraying potatoes, in comparison with home-mixed Bordeaux, and is co-operative between the Department of Botany, the farm department and the service organization of the Experiment Station. The complete absence of late blight in the year just past made impossible the measurement of the action of fungicides on this disease. Yield records indicated no appreciable stimulation of growth by the use of Bordeaux.

Department of Plant and Animal Chemistry.

Project 5. "Chemistry of arsenical insecticides."
Professor HOLLAND and Mr. DUNBAR.

Despite its name this project has practically become a study of the chemistry of insecticides and fungicides. Work under this project the past year included the preparation of Bulletin No. 201 in co-operation with the Departments of Entomology and Botany; and a large amount of analytical work done in co-operation with these same departments, with the Department of Pomology, and with the State Department of Conservation. Analytical work was done on concentrated lime-sulfur, lime-sulfur paste, dry lime-sulfur, Sulco V-B, Sander's dust, dry lead arsenate and NuRexo. Assistance was also given in fumigation experiments with hydrocyanic acid. Determination of arsenic in the bodies of dead bees was also made to determine the probability of death being caused by this substance.

Project 13. "A new method for the analysis of dry lime-sulfur mixtures."
Assistant Professor JONES.

Work on this project has been carried on at intervals for the past two years. Results are now being prepared in manuscript form, in order that the method may be critically examined as to its accuracy and usefulness.

Department of Entomology.

Project 1. "Studies of causes of burning of foliage by arsenicals."
Professor FERNALD and Assistant Professor BOURNE.

This project was started in 1908. Work has been completed and manuscript prepared presenting in graphic form the results of over 1,500 separate observations on spray injury. This will be published as a station bulletin as soon as opportunity allows.

Project 12. "Determination of the best strength of lime-sulfur."

Assistant Professor BOURNE.

Work on this project was commenced in the spring of 1921. Results as yet are purely tentative.

Project 13. "Study of the possible injurious effects of Scalecide on trees."

Assistant Professor BOURNE.

This project requires a study of the cumulative effect of this spray. Work was commenced in the spring of 1921 with application of one dormant spray. Final report cannot be made until the fact of injury, or of no injury, be established.

Department of Pomology.

Project 11. "To test new spray materials as they become commercially important."

Professor SEARS and Assistant Professor GOULD.

This project was co-operative between the Department of Pomology and the Departments of Botany, Entomology and Plant and Animal Chemistry. The following materials were tested in 1921: —

Sulco V. B. (1920 and 1921 material).
Grasselli Lime Sulfur paste.
NuRexo Bordeaux powder.

These were tried in comparison with dry lime-sulfur and liquid lime-sulfur. All were used with arsenate of lead. The bud pink and calyx sprays were applied to several varieties, including Baldwins and McIntosh. All sprays, even the arsenate of lead alone, caused some burning of the foliage, but this was most serious where Sulco V. B. was used. The lime-sulfur paste was in poor mechanical condition, and there was considerable injury from the Bordeaux powder.

Annual Nutrition.

Animal Metabolism.

Department of Plant and Animal Chemistry.

Project 1. "A study of the chemistry of butter fat and the effect of food in modifying its chemical and physical character."

Professor Holland, Assistant Professor Archibald and Mr. Dunbar.

An exhaustive report has been prepared for publication on the studies relative to the influence of breed, period of lactation, and of the different oils and fats in the ration fed, on the composition of the resulting butter fat. This report includes: (1) composition of butter fat from mixed herd milk, grade Holsteins and grade Jerseys, on normal rations; (2) composition of butter fat from the milk of single animals, grade Holsteins and grade Jerseys, relatively fresh in lactation, on normal rations; (3) composition of butter fat from the milk of single animals of breeds stated, fresh, intermediate, and late in lactation, on a normal ration; (4) composition of butter fat from mixed milk, grade Holsteins, on a normal ration and with the addition of different oils and fats; (5) summary of data, together with such general deductions as seem warranted.

Digestibility of Feeding Stuffs.

Department of Plant and Animal Chemistry.

Project 2. "Digestion experiments."

Professor Lindsey and Assistant Professor Archibald.

The only investigation made under this definite project for the last calendar year was with feterita, a member of the milo maize group. Digestion work was carried on, however, under Projects 11 and 12 of this department.

Project 9. "Determining the digestibility and metabolizable energy in feeds for horses."

Professor Lindsey and Assistant Professor Archibald.

Work on this project has been completed, and the data obtained will shortly be assembled in manuscript form.

Project 11. "Determination of the chemical composition, digestibility and feeding value of kiln dried apple pomace."

Professor LINDSEY and Assistant Professor ARCHIBALD.

This project has been completed and results published as Bulletin No. 205 of the Experiment Station.

Project 12. "Attempting to improve the nutritive value of grain hulls."

Professor LINDSEY and Assistant Professor ARCHIBALD.

There has been considerable activity on this project. Data concerning the effect of chemical treatment on oat hulls and rice hulls have been obtained. It is expected to do further work with cottonseed hulls, barley hulls and flax shives. In view of the large amount of these products now produced in the milling industry of the country, and the extent to which such products are used in Massachusetts agriculture, the economic significance of the project is apparent.

ANIMAL FEEDING.

Department of Plant and Animal Chemistry.

Project 10. "Experiments in feeding pigs."

Professor LINDSEY and Assistant Professor ARCHIBALD.

Work on this project was confined to the taking of records on feeding of different amounts of semi-solid and dried buttermilk. Results indicate these materials to be uneconomical when used for pork production.

Project 16. "Vitamines as aids in the production of growth in pigs."

Professor LINDSEY.

This investigation was undertaken the past season in cooperation with the Department of Animal Husbandry. The work was under the immediate oversight of a graduate student, with expectation that it would form a part of a thesis for advanced degree. The use of green feed, either because of its service as a vitamine carrier, or for other reasons, improved growth. Corn germ meals were found unsatisfactory as carriers of vitamines.

Miscellaneous.

Department of Plant and Animal Chemistry.

Project 3. "Summer forage crops."

Professor Lindsey.

Work the past season was confined to the growing of corn and soy beans, alone and in combination, at different planting rates, and by different planting methods. The past history of the land used in the experiment, however, was such as to render impossible the drawing of definite deductions from this work.

Project 4. "Record of the station herd."

Professor Lindsey.

This is a continuing project in which accurate record is kept of the food consumed by individual cows, the amount of milk produced, the determination of milk solids and milk fat, and estimation of the food costs. As records accumulate this work is of increasing value.

Studies of Heredity in Poultry.

Department of Poultry Husbandry.

Project 1. "Broodiness in poultry."

Professor Goodale.

The line of attack includes the following: (1) Elimination of broodiness from the high lines through suitably tested matings. The percentage of broodiness has now been reduced to about forty. One family of eleven daughters has been produced apparently entirely free from broodiness, and another and highly inbred family shows but one broody member out of fourteen daughters. (2) Production of intensely broody race. (3) Investigation of the effect of crossing. This work is supplemented by physiological studies of the different organs associated with the phenomenon of broodiness.

Project 2. "To determine the mode of inheritance of various characters of poultry, and to study factors governing form and function."

Professor Goodale.

The previous project really represents an attack on one phase of this larger problem. In studying the inheritance of fecundity it was found that this character was split up into at least five major elements. Through treating each of these elements as units steady progress is being made in breeding for increased egg production. In addition to the foregoing, considerable work is being done on the study of various factors of inheritance and morphogenesis.

Animal Disease Control.

Department of Veterinary Science.

Project 2. "Methods of diagnosis of bacillary white diarrhea."

Professor Gage.

This project is being brought to a close, and results and interpretations are being compiled in manuscript form. It is expected that the manuscript will be published as a station bulletin some time during the coming year.

Project 3. "Study and control of poultry diseases in College and station flocks."

Assistant Professor Lentz.

This represents a record of control measures taken to wipe out disease conditions as occurring in the College poultry flock in the spring and summer of 1920, together with a study of the effectiveness of the methods used.

Project 4. "Study and control of bovine abortion and complications in the College herd."

Assistant Professor Lentz.

As with the foregoing, this project is largely a record of means taken to meet an outbreak of bovine abortion in the College herd. Records to date indicate a very great decrease in the virulency of the disease.

Human Food.

Department of Microbiology.

Project 1. "Microbiological investigations in milk."
Mr. AVERY and Mr. NEILL.

The past year saw practical completion attend several undertakings bearing upon the presence of Streptococci in milk, and their relation to other Streptococci found in disease. A report on one of these undertakings has been accepted for publication in "Dairy Science." This deals with a study of the groupings of Streptococci known as lactic Streptococci. Another piece of work which is nearly ready for publication consists of the study of these Streptococci in their relation to growth conditions and reducing values upon methylene blue, a reagent which has been employed for a number of years in certain dairy determinations.

Another aspect of this study deals with the proteolytic action of the lactic Streptococci as compared with other Streptococci and their capacity to produce, particularly, amino acids and ammonia.

Project 3. "Canning investigations in the light of normal and resistant organisms in continuous, fractional and pressure methods of sterilization."
Professor MARSHALL and Mr. McCRIMMON.

Further work on this project was done during the year in the study of the thermal death point in connection with canning. Progress, however, has been delayed through lack of the necessary assistance.

Agricultural Economics.

Department of Agricultural Economics.

Project 1. "Local balance of trade in farm products."
Assistant Professor JEFFERSON.

This project was undertaken with a view to discovering quantities of farm products produced and consumed in several communities of the State, the quantities shipped out, and the methods of marketing local farm produce. The study was begun in Holyoke some time ago, and this year has been continued in Fitchburg. It is expected that the study will be taken up in at least two other communities during the coming year.

Project 2. "Methods and cost of distribution of tobacco, onions and potatoes."

Professor Cance and Assistant Professor Jefferson.

Work under this project has been continued and records taken on the production and distribution of Connecticut valley onions during the years which have elapsed since the publication of Bulletin No. 169, "The Supply and Distribution of Connecticut Valley Onions." No work has been done during the past year on either tobacco or potatoes.

Meteorological Studies.

Department of Meteorology.

The recording day by day of meteorological phenomena, and the publishing of monthly summaries for distribution to parties interested has been continued. The year just closed was the thirty-third over which this work has continued. When combined with the records taken by the late Professor Snell, the station has an unbroken meteorological record of eighty-six years. Work of this kind becomes more and more valuable as such records accumulate.

Department of Entomology.

Project 11. "Study of area of the late frosts as shown by insect distribution."

Professor Fernald.

This is a continuing project, which aims to establish the correlation of certain late frost areas in the State with the presence or absence of certain insects. Little work was done this past year on account of lack of opportunity.

Cranberry Station.

Project 3. "Weather observations with reference to frost prediction."

Professor Franklin.

As in past years, the United States Weather Bureau has telegraphed daily reports from the district forecaster in Boston. Further study has been made as to correlation of certain meteorological conditions and frost probability. Through the co-operation of cranberry growers, and under financial support from their association, frost warnings are now being sent out whenever conditions necessitate.

CONTROL AND REGULATIVE WORK.

By State law, the enforcement of four different control or regulative laws is vested in the Experiment Station. These are the fertilizer control, provided for under sections 250 to 261 of chapter 94 of the Revised Laws of Massachusetts; the feed control, provided for under sections 225 to 235 of the same chapter; the poultry disease elimination, provision for which is found in sections 17 and 21 of chapter 75 of the same laws; and the inspection of dairy glassware and examination of milk testers, provided for in sections 25 to 31 of chapter 94.

The immediate responsibility for the execution of all of the above laws is vested in the Department of Plant and Animal Chemistry, with the exception of the poultry disease elimination law, for which the Department of Veterinary Science is the controlling agency. Detailed reports of operations under these various control laws follow.

Fertilizer Control.

H. D. Haskins, Chemist in Charge,

L. S. Walker, Assistant Chemist, R. W. Swift, Analyst.

During the season of 1921, 109 manufacturers, importers and dealers have secured certificates for the sale of 548 brands of fertilizer and fertilizing materials and 31 lime compounds. The following statistics have been gathered with reference to the year's inspection: 10,567 tons of fertilizer and fertilizing materials were inspected, necessitating the sampling of 21,859 sacks; 199 towns were visited; 1,504 samples, representing 556 distinct brands, were drawn from stock found in the possession of 546 agents or owners; 302 agents were called upon who had discontinued handling fertilizer; 783 analyses were made. In case of lime compounds, 1,106 tons were inspected, necessitating the sampling of 1,194 sacks; 39 towns were visited; 49 samples, representing 27 distinct brands, were drawn from stock found in the possession of 48 agents or owners; 28 analyses were made.

The following table shows the number of brands of the different materials which were registered and sampled, as well as the number of analyses made: —

Materials.	Brands registered.	Brands sampled.	Analyses made.
Complete fertilizers	300	287	308
Ammoniated superphosphates	49	38	43
Superphosphates with potash	7	6	7
Ground bone, tankage and dry ground fish	55	50	70
Nitrogen compounds	77	63	223
Phosphoric acid compounds	32	30	33
Potash compounds	16	14	19
Wood ashes	3	3	29
Pulverized animal manures	11	9	23
Lime compounds	31	27	28
Totals	581	527	783

Full details of the fertilizer inspection work may be found in Bulletin No. 16, Control Series, published in November, 1921; and of the lime inspection work, in Bulletin No. 17, Control Series, published in December, 1921.

Fertilizer Grades and Tonnage sold in Massachusetts from Jan. 1 to July 1, 1921.

From Jan. 1 to July 1, 1921, there were 54,370 tons of commercial fertilizer and fertilizing materials sold in Massachusetts, divided as follows: —

	Tons.
Mixed fertilizers	37,579
Unmixed fertilizing materials	15,073
Pulverized natural manures	1,718

The grades and tonnage of the mixed fertilizers are shown in the following tables, which are arranged to show in the order of their largest tonnage the various grades of (1) high and low analysis complete fertilizers, (2) high and low analysis ammoniated superphosphates and superphosphates with potash, and (3) unmixed fertilizer materials: —

TABLE 1. — *Complete Fertilizers.*

High Analysis (14 Per Cent or over of Available Plant Food).			Low Analysis (less than 14 Per Cent of Available Plant Food).		
Grade.	Tonnage.	Brands.[1]	Grade.	Tonnage.	Brands.[1]
4-8-4	9,484	38	2-8-3	3,261	23
3-8-4	5,915	27	2-8-2	2,726	35
3-9-2	1,527	8	1-8-2	890	9
3-8-3	1,075	9	5-4-4	707	-
4-8-6	1,016	15	5-4-3	522	11
5-4-5	737	12	1-10-1	252	5
6-6-4	606	8	4-4-4	213	-
3-10-3	540	5	1-7-1	184	-
5-8-7	489	8	3-8-2	126	-
3-8-6	485	5	6-4-3	112	-
2-10-4	437	-	3-6-4	87	-
6-12-6	293	-	5-6-1	85	-
4-7-5	285	-	3-6-3	61	-
5-8-4	260	-	4-7-2	58	-
6-8-4	229	-	2-8-1	42	-
6-6-6	218	-	1.22-3-1	33	-
5-8-5	216	5	1.22-3-2	33	-
10-3-4	198	-	1.22-3-3	33	-
4-8-7	171	6	Miscellaneous	120	
5-8-6	166	-			
5-9-4	130	-			
2-8-4	119	-			
7-12-6	107	-			
7-4-4	104	-			
6-4-4	66	-			
2-8-5	64	-			
5-6-5	61	-			
10-8-8	38	-			
6-4-15	37	-			
5-7-2	36	-			
5-6-3	35	-			
5-6-4	25	-			
5-5-4	24	-			
5-4-15	19	-			
3-12-3	17	-			
Miscellaneous	233				
Total . .	25,462	-	Total . .	9,545	-

[1] Where less than five brands of a given grade are registered, the number is not given in this table.

TABLE 2. — *Ammoniated Superphosphates and Superphosphates with Potash.*

High Analysis (14 Per Cent or over of Available Plant Food).			Low Analysis (less than 14 Per Cent of Available Plant Food).		
Grade.	Tonnage.	Brands.[1]	Grade.	Tonnage.	Brands.[1]
4-10-0	307	11	5-4-0	645	-
0-4-15	133	-	3-10-0	365	-
0-12-2	79	-	7-6-0	264	-
0-10-4	73	-	4-8-0	134	-
Miscellaneous	19	-	6-4-0	121	-
			5-8-0	107	-
			6-6-0	88	-
			3-9-0	59	-
			10-3-0	54	-
			5-6-0	44	-
			2-8-0	29	-
			4-3-0	15	-
			Miscellaneous	36	
Totals .	611	-	Total .	1,961	-

TABLE 3. — *Unmixed Fertilizing Materials.*

Material.	Tonnage.	Brands.[1]
Cottonseed meal	6,033	37
Acid phosphate	3,385	29
Nitrate of soda	1,875	25
Pulverized natural manures	1,718	11
Ground bone	860	28
Wood ashes	691	-
Dry ground fish	661	14
Ground tankage	535	19
Sulfate of ammonia	442	10
Sulfate of potash	176	6
Muriate of potash	170	8
Castor pomace	66	-
Nitrate of potash	62	-
Raw ground phosphate	48	-
Precipitated bone	39	-
Kainit	25	-
Dried blood	5	-
Totals	16,791	-

[1] Where less than five brands of a given grade are registered, the number is not given in this table.

An analysis of the foregoing tables reveals the following facts: —

1. Sixty-nine per cent of the total tonnage sold was made up of mixed goods, and 31 per cent of chemicals and unmixed fertilizer by-products.

2. Of the 37,579 tons of mixed goods sold, 93 per cent were complete fertilizers and 7 per cent were ammoniated superphosphates and superphosphates with potash.

3. Of the 35,007 tons of mixed complete fertilizers, about 73 per cent were high analysis (14 per cent or over of available plant food) and 27 per cent low analysis fertilizers (less than 14 per cent of available plant food).

4. The 25,462 tons of high analysis complete fertilizers were, with the exception of 233 tons, furnished by thirty-five grades of fertilizer, that is, formulas having their plant food present in various proportions. About 88 per cent of the total tonnage of the high analysis mixtures was furnished by eleven grades of fertilizer, and about 79 per cent of the balance was furnished by thirteen other grades; or, expressed in another way over 97 per cent of the total tonnage of high analysis fertilizers was furnished by twenty-four grades.

5. The 9,445 tons of low analysis fertilizers were, with the exception of 120 tons, furnished by eighteen grades of fertilizer, and over 94 per cent of this tonnage was furnished by ten grades of fertilizer.

6. In case of the ammoniated superphosphates, of the 2,278 tons sold, over 86 per cent were low analysis goods. The tonnage of high analysis ammoniated superphosphates was furnished by one grade, and 87 per cent of the tonnage of the low analysis was furnished by seven grades.

7. Thirty-six per cent of the total tonnage of mixed fertilizer was derived from grades recommended for the East by the soil improvement committee of the National Fertilizer Association; and over 64 per cent of the total tonnage deviated by 1 per cent only, in nitrogen, phosphoric acid, or potash, as the case might be, from grades thus recommended.

8. With reference to chemicals and crude stock materials, the distribution of the tonnage was as follows: about 57 per cent of the total tonnage was nitrogen products; about 26

per cent, phosphoric acid products; and about 7 per cent, potash products. In all probability the tonnage of unmixed potash salts is abnormally low on account of the high prices which have prevailed for this ingredient.

With reference to the uneconomic phase of the purchase of low analysis fertilizers, it is estimated that the plant food bought by the Massachusetts farmers in 1921 in form of low analysis fertilizers cost them about $94,000 more than if it had been bought in the form of high analysis mixtures. To this should be added the extra cost of freight, cartage and labor for application to the land.

Feed Control.

P. H. Smith, Chemist in Charge.
Miss E. M. Bradley, Analyst.

During the year, 1,121 samples of feeding stuffs, collected of dealers and manufacturers, were analyzed and are reported in Bulletin No. 15 of the Control Series. Two hundred and twenty-one dealers located in 136 towns were visited at least once. One thousand, three hundred and forty-nine brands of feeding stuffs were registered for sale in Massachusetts by 258 dealers. The purchase of an automobile for the use of the inspector not only enabled him to save much time, but also made it possible to visit more frequently stores not easily accessible on account of their distance from railroad and trolley lines.

In common with other business, the grain trade has been extremely unsettled, and in order to meet a falling market much feed has been sold by the retailer at less than the wholesale price at the time of purchase.

No serious cases of adulteration and misbranding were discovered. While it is true that some feeders may not use the best of judgment in their selection of feeding stuffs offered, the guarantee requirement of the feeding stuffs law including a statement of ingredients, enables the purchaser to determine the quality of the goods he purchases. The law does not prohibit the sale of any material which is not actually injurious, but simply requires that such information be furnished the purchaser, by means of the guarantee, as to enable him to know just what he is buying.

Poultry Disease Elimination Law.

George E. Gage, in Charge.
O. S. Flint, Specialist in Charge.

During the year, 24,718 breeding hens have been tested under the poultry disease elimination law, distributed in Worcester, Middlesex, Norfolk, Essex, Plymouth, Bristol, Hampshire, Hampden, Franklin and Berkshire counties. Of this number, 10,897 were Rhode Island Reds, 3,033 White Rocks, 1,890 Barred Rocks, 5,539 White Leghorns, 974 White Wyandottes, and 2,385 miscellaneous. The infection, as indicated by the agglutination test, has been 12.5 per cent for the total 24,718. Twenty-five flocks were found free from infection. The demand for this testing work is increasing all the time, and in a few years, if funds are available to perfect the epidemiological phases of the problem, great benefits will result. A glance at the United States census report for 1920, under the heading of "Massachusetts Industries," will show that there were by census more than 1,455,000 chickens in the State, the value of poultry products being $10,700,000 per year. It would appear from these figures that the State would be justified in the yearly expenditure of $10,000 to protect and improve such an industry.

The Dairy Law.

P. H. Smith, Chemist in Charge.

The dairy law, so called, requires operators of the Babcock test, where such test is used as a basis of payment for milk or cream, or for the purposes of inspection, to secure a certificate of proficiency from the Experiment Station. Forty-six applicants were given the required examination and received certificates. The act requires, also, that all glassware used by licensed operators be tested for accuracy and so marked. Out of a total of 4,664 pieces of glassware tested only 6 have been condemned. In addition to the preceding, an annual inspection of machines and apparatus is also required. This inspection was carried out by Mr. J. T. Howard, authorized deputy, who visited six creameries, fifty milk depots and thirty-five milk-inspection laboratories. Reinspections on account of repairs ordered will be necessary at fourteen places. It is of interest to note that, in general, machines were in greater need of repair than for any time in recent years, presumably on account of the present business depression which caused owners to defer making repairs as long as possible. The recent explosion of a machine in a milk plant near Boston, which resulted in serious injury to two men, should serve as a warning to those using machines out of repair.

TESTING OF PURE-BRED COWS FOR ADVANCED REGISTRY.

P. H. SMITH, CHEMIST IN CHARGE.

On account of the ever-increasing amount of advanced registry work, it has become necessary to engage a clerk to aid in general supervision and in the keeping of records. Not less than ten and as many as fifteen men have been employed in making the two-day, monthly tests. For the year ending Dec. 1, 1920, 5,820 two-day tests were reported; for the year just past, 7,250 were reported, — an increase of 1,430 over the previous year. The number of cows on yearly test increased in one year from 519 to 676, the number of farms from 72 to 93.

The number of short-time tests for the Holstein-Fresian Association did not equal the number conducted during the preceding year. Statistics for the Holstein work follow: —

Number of farms visited	30
Supervisors employed	26
Reports turned in:	
60-day	4
30-day	50
14-day	29
7-day	152

Summary of Two-day Test Work, December, 1920, through November, 1921.

Month.	Number of Supervisors, Whole or Part Time.	Number of Cows tested.						Number of Herds visited.					
		Guernsey.	Jersey.	Ayrshire.	Short-horn.	Holstein.	Totals.	Guernsey.	Jersey.	Ayrshire.	Short-horn.	Holstein.	Totals.
December	12	192	115	101	28	78	514	37	11	12	3	12	75
January	12	212	119	113	23	72	539	42	12	14	2	14	84
February	15	221	122	103	21	85	552	43	13	13	2	14	85
March	13	223	132	106	20	64	545	43	11	13	2	13	85
April	10	242	132	122	21	78	595	41	14	14	2	12	83
May	13	254	136	140	18	79	627	43	13	14	2	16	88
June	11	256	131	138	21	94	640	46	13	13	2	17	91
July	11	237	135	122	19	109	622	45	14	12	2	15	88
August	11	241	136	120	20	101	618	41	15	12	2	15	85
September	11	248	170	118	18	106	660	37	16	12	2	17	84
October	15	257	147	119	20	119	662	40	16	13	2	19	90
November	15	262	150	133	20	111	676	43	15	14	2	19	93
Totals	-	2,845	1,625	1,435	249	1,096	7,250	-	-	-	-	-	1,031

ANALYTICAL AND DIAGNOSTIC SERVICE.

From the founding of the Experiment Station, work of this character has formed a large part of the service rendered to the people of the State. The work as now organized is carried on in the following departments: —

1. Department of Plant and Animal Chemistry, which has charge of the chemical analytical work.
2. Department of Botany, which performs certain analytical work with reference to seeds, and likewise a large amount of diagnostic work with reference to plant diseases.
3. Department of Entomology, which is subject to numerous calls on the diagnosis of insect troubles.
4. Department of Veterinary Science, which performs similar service with reference to animal diseases, and particularly poultry diseases.

A part of this work has definite investigational value. It is through the information gained in the diagnostic work that the Departments of Botany, Entomology and Veterinary Science are able to keep in touch with conditions all over the State. It must be remembered that the Experiment Station is expected to give State-wide service, but despite this it has no field organization. On the other hand, certain phases of the work are to a certain degree of commercial or personal service nature. This work is being discouraged. Since, however, cost-free service of this kind has been offered by the station for the past forty years, it is not possible to do away with this in any short period of time. The correspondence connected with the carrying on of this service is heavy, and is of a definite extension nature. It is probable that some of this work should be organized under the Extension Service rather than under the Experiment Station.

General Chemical Analytical Service.

Department of Plant and Animal Chemistry,
Dr. J. B. Lindsey, Head.

The work for the year ending Nov. 30, 1921, included the following. For comparison, the records of 1919 and 1920 are also included.

Numerical Summary of Laboratory Work.

	1919.	1920.	1921.
Alcohol determinations	–	–	4
Arsenic determinations	3	2	2
Breast milk	1	2	2
Ash analysis of fodder articles	–	–	2
Cider for soluble copper	–	9	–
Coal	–	–	1
Cream	442	378	205
Evaporated milk	1	–	–
Feedstuffs	231	145	196
Fertilizers	157	100	173
Fungicides	–	–	12
Ice cream	–	1	4
Insecticides	7	9	5
Lime products	7	6	9
Lubricating oil	–	–	2
Milk	498	344	587
Semi-solid buttermilk for dissolved metals	–	–	1
Soils for lime absorption capacity and organic matter.	137	137	64
Soils for complete or partial chemical analysis	5	20	15
Tobacco	–	12	–
Urine	–	–	2
Vinegar	7	7	14
Water	60	60	63
Weed eradicator	–	–	1

In connection with experimental work, the following analyses were made: —

	1919.	1920.	1921.
Milk	139	168	200
Feedstuffs	22	114	131
Feces	49	49	43
Urine	25	14	14
Dry matter determinations on pot and plot experiments.	671	288	416
Nitrogen determinations on pot experiments	123	96	60
Phosphoric acid determinations on pot experiments.	12	44	66
Potash determinations on pot experiments	–	48	–
Oven-dried weights	580	–	133

Decrease in certain of the above items, notably that in the number of soil analyses, is due to definite attempt on the part of the station to discourage requests for this kind of service.

Analysis, Germination Tests and Separation of Seeds.

Department of Botany,
Prof. A. V. Osmun, Head.

Germination Tests.

During the year germination tests were made on 448 samples of seeds, as listed below. In nearly all cases the tests were made in duplicate, thus doubling the time, labor and expense involved.

Vegetables.

Beans	4	Endive	3
Beets	2	Lettuce	3
Cabbage	5	Parsley	3
Carrots	33	Pea	1
Cauliflower	1	Radish	4
Celeriac	1	Spinach	33
Celery	14	Tomato	14
Corn, sweet	1	Turnip	4
Dandelion	1		

The 127 samples tested were submitted from 4 cities and towns of the Commonwealth, and 1 from another experiment station.

Field Crops.

Alfalfa	1	Corn	3
Barley	2	Millet	3
Beans, soy	2	Oats	3
Beets, mangel	1	Onions	207
Clover, alsike	2	Rape	1
Clover, red	2	Tobacco	62
Clover, sweet	3	Vetch	1

Of the total of 293 samples tested, 6 were submitted from other experiment stations, 156 from 21 villages, towns and cities of the Commonwealth, and 131 were tested for outside parties but for the benefit of resident growers.

Grasses.

Canada blue	1	Red fescue	4
Creeping bent	1	Redtop	5
Orchard	1	Timothy	1

The samples were received from 4 cities and towns of the Commonwealth, and 4 from other experiment stations.

Miscellaneous.

Balsam fir	2	Pine (White)	5
Hemlock	1	Sage	1
Pine (Austrian)	1	Spruce (Canada White)	1
Pine (Red)	1	Spruce (Norway)	1
Pine (Scotch)	1	Spruce (Wisconsin White)	1

The samples came from 2 towns in the Commonwealth.

Purity Tests.

Of the 41 samples tested, 32 were submitted from 7 cities and towns of the Commonwealth, and 9 from other experiment stations.

Field Crops.

Alfalfa	1	Clover, white	1
Barley	2	Millet	3
Clover, alsike	2	Oats	3
Clover, red	2	Vetch	1
Clover, sweet	3		

Grasses.

Canada blue	1	Orchard	1
Creeping bent	1	Red fescue	4
Mixed grasses for putting greens	10	Redtop	5
		Timothy	1

Tobacco Seed Separation.

Seventy-seven samples of tobacco seed were submitted from 15 towns and villages in the tobacco-growing section of the State.

Diagnostic Service in Animal Pathology.

Department of Veterinary Science,
Dr. G. E. Gage, Acting Head.

During the year, 636 different sets of diseased material were submitted to the departmental laboratories for examination. In most cases these materials were accompanied by letters requesting suggestions for treatment. This has involved the classification and recording of a large amount of correspondence. A large percentage of the materials submitted have been examined bacteriologically, serologically and pathologically. Diagnosis reports and suggestions were made concerning cases of the following diseases: —

Abdominal hemorrhages
Anemias
Antresias
Apoplexy
Ascites
Aspergillosis
Bacillary white diarrhea
Biliary obstructions
Biological atrophy
Cachexia
Calf scours
Caseation necrosis
Cercomoniasis
Chicken-pox
Choleolithiasis
Chronic atrophy
Chronic indigestion
Coccidiosis
Congestion of the lungs
Cutaneous emphysema from ruptured air sacs
Diphtheritic roup
Duck septicæmia
External parasites
Fatty metamorphosis of liver
Fermentative infection of gastro-intestinal tract
Fibromæ
Fowl cholera
Fowl typhoid
Gangrenous dermatitis
Gaseous enteritis
Impaction of crop
Impaction of duodenum and intestines
Infarction of kidney
Infectious necrosis of canaries
Intestinal congestion
Intestinal diarrhea
Intestinal intussusception
Intestinal parasites
Jaundice
Laryngitis
Leukemia
Limber neck
Lung strongylosis of pigs
Multilocular cysts of ovary
Nasal catarrhs
Necrosis of liver
Nephritis
Nodular tæniasis
Occlusion of bile duct
Œdema of prepuce in sheep
Œsophageal obstruction
Ovarian inflammation
Ovarian obstruction
Ovarian tumors
Paralysis
Pericarditis
Peritonitis

Pneumonia	Streptococcic mastitis in cows
Poisoning	Streptococcus infection
Pressure atrophy	Suffocation
Rachitis	Superficial erythema
Ruptured oviduct	Superficial ulcers of skin
Sarcoptes mutans and Sarcoptes levis infestation	Thrombosis
Septicæmia	Traumatic tumors
Sporadic dysentery in calves	Avian tuberculosis
Staphylococcus infections of ovary	Gizzard ulcers in poultry
Stomach worms in sheep	Uremia
Streptococcic arthritis	Uric acid arthritis
	Visceral gout

In addition, a large amount of diagnostic service was given to the animals of the College and Experiment Station flocks and herds. The following represents the cases examined for disease during the past year: —

Horses.	Cattle.	Sheep.	Pigs.
Arthritis.	Laceration abomasum.	Dermatitis.	Arthritis.
Bronchitis.	Arthritis.	Dystokia.	Dystokia.
Cartilage infections.	Castration.	Impaction.	
Castration.	Dystokia.	Indigestion.	
Coronitis.	Calf diarrhea.	Mastitis.	
Labial retention cysts.	Erythema.	Pneumonia.	
Float molars.	Eversion of vagina.	Post-mortem examinations.	
Colic.	Eversion uterus.		
Influenza, vaccine administration, all farm horses.	Indigestion.		
Laminitis.	Mastitis.		
Omphalo-phlebitis.	Parturient paresis.		
Pervious urachus.	Pericarditis.		
Pneumonia.	Pododermatitis.		
Strangles.	Ringworm.		
Traumatisms.	Traumatisms.		
Fistulous withers.	Post-mortem examinations.		
Post-mortem examinations.	Subcutaneous tuberculin testing of both herds.		
	Ophthalmic and intradermal check tests.		

The Department of Veterinary Science has manufactured and standardized its own diagnostic sera, twenty-two different types being made in the year in question. These sera are used both in the diagnostic work and in the control studies, and represent a saving to the institution, over the cost of equivalent kinds and amounts if purchased, of about $2,500. Sera of these kinds are suitable for use for about one year. Each year the process of preparation must be repeated and new standards obtained.

It is worthy of note that practicing veterinarians are typically unable to give service with reference to poultry diseases. It is partly due to this fact that commercial poultry raisers have sometimes been unable to combat the attacks of contagious disease. The Experiment Station now performs in this diagnostic work a unique service, which is not duplicated by any commercial organization, or, in fact, by any organization in New England. How far the station should go in doing this work is a question. There is no doubt, however, that to date it has resulted in greatly bettering conditions in what is in Massachusetts a large taxpaying agricultural industry.

Insect Conditions of the Year 1921 in Massachusetts.

Department of Entomology,
Dr. H. T. Fernald, Head.

In most ways the year 1921 was an ordinary one, so far as insects are concerned, in this State, only two instances of an unusual character developing.

The first of these was a rather serious but quite local outbreak of the seed-corn maggot (*Hylemyia cilicrura* Rond.) in the onion fields in and near Whately, Hatfield and Sunderland. This insect, so far as any records thus far found go, has never before been reported as injuriously abundant in the State.

The onion fields affected were planted early in April, and because of cold, wet weather the plants were just appearing by the first of May, and were very few in number. Examination at that time showed an abundance of the maggots attacking the sprouts soon after they had started, and working back to the seed itself. From larvæ collected in the fields the adults were raised and their identity verified. It was noticeable that the fields fertilized with cottonseed meal were the ones chiefly infested, no maggots being found in those not so fertilized, even when adjacent to affected ones. No trace of the insect was found in the cottonseed meal itself before its use. It was necessary to replant most of the affected fields, which, taken together, probably represented over 100 acres, but no injury by the insect was noted in such replanted fields.

The second outbreak was that of the corn ear worm (*Chloridea obsoleta* Fab.). This insect is usually heard from by two or three inquiries about it each year, nearly always from the southeastern part of the State. Last fall the first report was received September 13 from Greenfield, and from then until November 7 letters about it came in large numbers. From the inquiries received, it was present, generally very abundant, in all parts of the State except Berkshire County, where only four locations were learned of, these being one in West Stockbridge, two in Pittsfield and one in Williamstown. It was probably present elsewhere in the county also.

Sweet corn suffered most from this pest, particularly the yellow types, though ensilage, field and pop corn were also attacked. Flint corn was only slightly injured. In some cases a 95 to 100 per cent loss was reported. One case of injury to geraniums was also met with. Through the co-operation of county farm bureau agents, reports of the general, and in many cases the detailed, conditions in the different counties were received, indicating a very general and serious degree of injury. At the Experiment Station living active larvæ of nearly all ages were found on November 5, but ten days later, after two slight snowstorms and the accompanying cold weather, no living, but numerous dead larvæ, were present. Apparently those which had not gone into the ground before this time could not survive this cold weather, and the mortality must have been large.

The striped cucumber beetle was unusually abundant last spring, while the common apple aphids, seemingly because of two heavy frosts just after most of them had hatched, were so reduced in abundance in many parts of the State that nicotine sulfate was omitted from the delayed dormant spray by a number of orchardists without any injury by the aphids resulting. A case of mole crickets feeding on potatoes was reported in September. This insect is seldom observed doing injury in Massachusetts. The birch-leaf skeletonizer, after having been practically absent for about ten years, reappeared abundantly enough to be noticeable in the eastern part of the State, but no more than usual west of Worcester.

Diagnosis of Insect Troubles.

During the year ending the last of November, 1921, diagnosis of 616 cases of insect injury were made on insects and insect damage reported from 226 different villages, towns and cities in the Commonwealth. In addition to this there were 222 telephone or office calls on the same subject, and 39 visits by members of the staff at the request of owners, as well as a large amount of miscellaneous correspondence relating to insecticides and spray machinery. This again is a service which has no commercial counterpart, and which must be rendered by the station or not at all. Farmers as individuals, moreover, are unable oftentimes to either recognize or combat such troubles. Apparently, therefore, the Experiment Station must continue to give this service. The following table is presented, showing the range of subjects treated in this work, and the geographical range from which inquiries come: —

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921.

[Figures in parentheses indicate the number of cases of injury by the same insect reported from the town; where there is no figure only one case of injury was reported.]

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis.			Reported from —
		Letter.	Phone.	Total.	
Abbott's sphinx moth	*Sphinx drupiferarum*	1	–	1	Duxbury.
Angle worms	– –	1	1	2	Southwick.
Ants	Formicidæ	21	5	26	Boston (2), Boylston, Boylston Center, Cambridge (2), Clinton, Dedham, Franklin, Holyoke (3), Lowell, Millville, New Bedford, Saugus, Southborough, Watertown, Whitman, Chicago, Ill., Elizabeth, N. J.
Ants, black	Formicidæ	3	–	3	Easthampton, North Dana, Stoughton.
Aphis, root	Aphididæ	1	–	1	Boston.
Apple aphis	*Aphis pomi*	1	–	1	Westfield.
Apple leaf roller	*Archips* sp.	–	1	1	– – –
Apple tree borer	*Saperda candida*	6	–	6	Ashburnham, Becket, Boston, Greenfield, Shelburne Falls, Wakefield.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis.			Reported from —
		Letter.	Phone.	Total.	
Asparagus beetles	*Crioceris asparagi*	1	–	1	Sharon.
Asparagus beetles	*Crioceris 12-punctata*	1	1	2	Sharon.
Asparagus miner	*Agromyza simplex*	1	–	1	East Milton.
Bag worms	Psychidæ	1	–	1	Walpole.
Bark beetles	Scolytidæ	1	–	1	Waltham.
Bark miner	– –	–	1	1	– – –
Bean caterpillar	*Plathypena scabra*	1	–	1	Pittsfield.
Bean weevil	*Bruchus obtectus*	24	4	28	Beverly, Bradford, Conway, Fall River, Framingham, Great Barrington, Greenfield, Kingston, Lowell, North Adams, North Wilmington, Peabody, Pittsfield, Reading, Salem, Shelburne Falls, Springfield (2), Turners Falls, Westfield, West Medford, West Natick, Williamsburg, Winchendon.
Bedbug	*Cimex lectularius*	3	7	10	Chicopee, Weymouth, Atkinson, N. H.
Bees and beekeeping	– –	30	58	88	Abington, Amesbury, Amherst, Athol, Becket, Boston (5), Chelsea, Chicopee, East Gardner, Hatchville, Holden (2), Lunenburg, Mansfield, North Brookfield, Orleans (2), Saugus, South Hadley (2), Springfield, Wakefield, Wellesley Farms, Worcester, Medina, Ohio, Toronto, Ont.
Bee diseases	– –	1	1	2	Boston.
Beetles	Coleoptera	2	–	2	Somerville, Hyannis.
Birch-leaf skeletonizer	*Bucculatrix canadensisella.*	2	–	2	Prides Crossing, Worcester.
Blister beetles	Meloidæ	1	–	1	Montgomery.
Blotch leaf miner	*Lithocolletes* sp.	1	–	1	Boston.
Blow fly	*Calliphora vomitoria*	1	–	1	Lynn.
Borers	– –	5	–	5	East Northfield, Lee, Littleton, Palmer, Southborough.
Borers	Cerambycidæ	1	–	1	Lenox.
Bronze-birch borer	*Agrilus anxius*	1	–	1	Cleveland, Ohio.
Brown-tail moth	*Euproctis chrysorrhœa*	5	–	5	Deerfield, Malden, North Wilbraham, Oxford, Rowley.
Brown fruit chafer	*Euphoria inda*	2	–	2	Shelburne Falls, Worcester.
Bruchid larvæ	*Bruchus* sp.	1	–	1	Stanford University, Cal.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Buffalo moth	*Anthrenus scrophulariæ.*	3	–	3	Springfield (2), Waverly.
Cabbage looper	*Autographa brassicæ*	1	–	1	Arlington.
Cabbage maggot	*Hylemyia brassicæ*	3	1	4	Arlington, Northampton, Ottawa, Ont.
Cabbage worms	*Pontia rapæ*	–	1	1	– – –
Calosoma beetles	*Calosoma* sp.	2	–	2	East Bridgewater, Medfield.
Caddis fly larvæ	Trichoptera	3	–	3	Plainfield (2), Ithaca, N. Y.
Carpet beetles	*Anthrenus scrophulariæ.*	1	–	1	Boston.
Caterpillars	Lepidoptera	1	–	1	Wilmington.
Cecropia moth	*Samia cecropia*	5	–	5	Boston, Littleton, Middleton, Waquoit, Woronoco.
Cerambycid pupa	Cerambycidæ	1	–	1	Cambridge.
Chermes sp.	*Chermes* sp.	1	–	1	Holyoke.
Chrysanthemum gall midge.	*Diarthronomyia hypogæa.*	1	1	2	Attleboro.
Cicada killer	*Sphecius speciosus*	1	–	1	Chicopee Falls.
Clear-winged moth	Sesiidæ	1	–	1	Brookfield.
Click beetles	Elateridæ	3	–	3	East Bridgewater (2), Somerville.
Clothes moths	– –	–	4	4	– – –
Clover mite	*Bryobia pratensis*	3	1	4	Boston, Holbrook, Springfield.
Codling moth	*Laspeyresia pomonella*	1	1	2	Harvard.
Confused flour beetles	*Tribolium confusum*	1	–	1	Richford, Vt.
Corn ear worm	*Chloridea obsoleta*	51	8	59	Arlington (2), Attleboro, Baldwinsville, Barre (2), Bernardston, Boston (2), Colrain, East Bridgewater, Fall River, Farnumsville, Fitchburg, Grafton, Greenfield (2), Griswoldville, Holden, Hudson, Ludlow (2), Milton, Monson, Natick, North Plymouth, Oakdale, Pepperell, Petersham, Readville (2), Rutland, Segreganset, Shrewsbury (2), Southbridge South Hadley Center, South Westport, Sterling Junction, Taunton, Turners Falls, Westborough, West Bridgewater, Westfield (2), West Medway, Worcester (2), Albany, N. Y., Little Compton, R. I., Newfane, Vt.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Cottony maple scale	*Pulvinaria vitis*	1	–	1	New York.
Cranberry girdler	*Crambus hortuellus*	2	–	2	East Wareham (2).
Currant aphis	*Myzus ribis*	1	–	1	Greenfield.
Currant borer	*Sesia tipuliformis*	1	–	1	Southborough.
Cutworms	Noctuidæ	4	1	5	East Bridgewater, Melrose, Springfield, Waltham.
Diving water beetle	Dytiscidæ	1	–	1	South Deerfield.
Earwig	Forficulidæ	1	–	1	Portland, Ore.
Eight-spotted forester	*Alypia 8-maculata*	2	–	2	Revere (2).
Elm leaf miner	*Kaliosphynga ulmi*	2	–	2	Ipswich (2).
European corn borer	*Pyrausta nubilalis*	15	3	18	Arlington (2), Boston, East Somerville, Georgetown, Ipswich, Medford, Methuen, Nahant, North Orange, Reading (3), Worcester, Jaffrey Center, N. H.
European fruit Lecanium.	*Lecanium cornis*	1	–	1	Whitman.
Fall canker worm	*Alsophila pometaria*	1	–	1	Raleigh, N. C.
Fall web worm	*Hyphantria cunea*	2	1	3	Cochituate, Waltham.
Fir sawflies	*Lophyrus abietis*	1	–	1	Harvard.
Fish worms	*Lumbricus* sp.	1	–	1	Gardner.
Flat-headed apple tree borer.	*Chrysobothris femorata*	1	–	1	Chelmsford.
Fleas	Siphonaptera	5	1	6	Auburn, Florence, Holyoke, Minot, Pittsfield.
Flea beetles	– –	–	3	3	– – –
Flies	Diptera	5	1	6	Bernardston, Boston, Hubbardston, Pittsfield, Northeast Harbor, Me.
Four-lined plant bug	*Poecilocapsus lineatus*	1	1	2	Newburyport.
Fruit tree bark borer	*Ecoptogaster rugulosus*	1	–	1	Andover.
Fuller's rose beetle	*Aragimus fulleri*	1	–	1	Montrose.
Gall flies	Cynipidæ	1	–	1	Holyoke.
Gall lice	Aphididæ	1	–	1	Lowell.
Gall midge	Itonididæ	3	2	5	Boston (2), Newtonville.
Gall midge flies	Itonididæ	1	–	1	Lenox.
Galls	– –	1	2	3	Madison, N. J.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Garden slugs	*Limax* sp.	2	–	2	East Bridgewater, Gardner
Giant water bug	*Lethocerus americanus*	2	–	2	Lynn, South Lincoln.
Golden oak scale	*Asterolecanium variolosum.*	1	–	1	Northampton.
Goldsmith beetle	*Cotalpa lanigera*	1	–	1	Haverhill.
Gouty oak gall	*Andricus punctatus*	1	–	1	Boston.
Grape-leaf folder	*Desmia funeralis*	1	–	1	Beverly.
Grapevine tomato gall	*Lasioptera vitis*	1	–	1	Wellesley.
Green fruit worm	*Xylina* sp.	1	–	1	Groveland.
Green-head fly	Tabanidæ	3	–	3	Boston, Gloucester, Ipswich.
Ground beetles	Carabidæ	1	–	1	Cambridge.
Gypsy moth	*Porthetria dispar*	10	1	11	Amesbury, Boston (3), Harvard, Malden, North Wilbraham, Rowley, Somerville, Wellesley Farms.
Hair worms	*Mermis* sp.	2	–	2	Lancaster, Rockland.
House centipede	*Scutigera forceps*	1	–	1	Boston.
Ichneumon flies	Ichneumonidæ	1	–	1	Bridgewater.
Imported currant worm.	*Pteronidea ribesii*	1	–	1	Wellesley.
Ips beetles	*Ips* sp.	1	–	1	Greenfield.
Lace bugs	Tingitidæ	1	–	1	Southwick.
Lady beetles	Coccinellidæ	1	–	1	Providence, R. I.
Larch case-bearer	*Coleophora laricella*	1	–	1	Northampton.
Larvæ	Lepidoptera	1	–	1	Geneva, N. Y.
Leaf hoppers	Cicadellidæ	2	4	6	Boston, South Lincoln.
Leaf rollers	*Archips* sp.	2	–	2	Beverly, Malden.
Leaf rollers	*Archips argyrospila*	1	–	1	Newton.
LeConte's sawfly	*Lophyrus lecontei*	1	–	1	Ipswich.
Leopard moth	*Zeuzera pyrina*	2	–	2	East Boston, Framingham.
Lilac borer	*Podosesia syringæ*	1	–	1	Plainville.
Linden mite gall	*Eriophyes abnormis*	1	–	1	Madison, N. J.
Long-tailed Thalessa	*Megarhyssa lunator*	3	1	4	Palmer, Sheldonville, Southwick.
Loopers	Geometridæ	1	–	1	Northampton.
Maggots	*Hylemyia* sp.	1	–	1	Mansfield.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Maple sawfly	*Caulacampus acericaulis.*	1	–	1	Boston.
May beetles	*Lachnosterna* sp.	1	–	1	Maynard.
Mediterranean flour moth.	*Ephestia kuhniella*	–	1	1	– – –
Mealy bugs	Dactylopius	2	–	2	Dorchester, Summit, N. J.
Mealy bug	*Rhizœcus falcifer*	2	1	3	Summit, N. J., New Brunswick, N. J.
Mellipedes	– –	1	–	1	Dover.
Miscellaneous	– –	4	30	34	Mansfield, Milford, Mount Hermon, Augusta, Me.
Miscellaneous apple insects.	– –	–	1	1	– – –
Miscellaneous aquatic insects.	– –	–	1	1	
Miscellaneous grain beetles.	– –	–	1	1	– – –
Miscellaneous grape insects.	– –	–	1	1	– – –
Miscellaneous onion pests.	– –	–	1	1	– – –
Miscellaneous pine insects.	– –	–	1	1	– – –
Mice	– –	2	1	3	Andover, Springfield.
Mite galls	Acarina	4	–	4	Monson, New Bedford, Pittsfield, Worcester.
Mite nail galls	Acarina	1	–	1	Royalston.
Mites	Acarina	8	3	11	Auburndale, Boston, Brookline, Haverhill, Holden, North Adams, Wakefield, Worcester.
Mite work	Acarina	1	–	1	North Wilmington.
Mole crickets	*Gryllotalpa* sp.	1	–	1	Fairview.
Moles	– –	2	2	4	Longmeadow, North Chester.
Mosquitoes	Culicidæ	5	–	5	Boston (2), Wilmington, Washington, D. C., Northeast Harbor, Me.
Mosquito larvæ	Culicidæ	1	–	1	Andover.
Mossy rose gall	*Rhodites rosæ*	1	–	1	Lee.
Nematode	*Heterodera radicola*	1	–	1	Boise, Idaho.
Northern tomato worm.	*Phlegethontius 5-maculata.*	1	–	1	Waltham.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis.			Reported from —
		Letter.	Phone.	Total.	
Oak blister midge	Itonididæ	1	–	1	Madison, N. J.
Onion maggot	*Hylemyia antiqua*	3	1	4	Arlington, Nantucket, Atkinson, N. H.
Onion thrips	*Thrips tabaci*	1	2	3	Arlington.
Ox warble	*Hypoderma bovis*	1	–	1	Ludlow, Pa.
Oyster-shell scale	*Lepidosaphes ulmi*	8	1	9	Ayer, Gloucester, Haverhill, Holyoke, Lenox, Upton, Wollaston, Ithaca, N. Y.
Palm insects	– –	–	2	2	– – –
Parasite	Hymenoptera	1	1	2	Springfield.
Peach tree borer	*Aegeria exitiosa*	2	2	4	Hyde Park, West Medford.
Pear-leaf blister mite	*Eriophyes pyri*	12	1	13	Boston, Brier, Brockton, Fitchburg, Hopkinton, Hyde Park, Lowell, Malden, North Wilbraham, Wakefield, Westfield, Providence, R. I.
Pear Psylla	*Psyllia pyricola*	5	–	5	Beverly, Leominster, Rowley, Salem, Wellesley.
Pentatomids	Pentatomidæ	1	–	1	Brookfield.
Pigeon Tremex	*Tremex columba*	1	–	1	Palmer.
Pine bark aphid	*Chermes pinicorticis*	4	–	4	Easthampton, East Northfield, Methuen, Williamstown.
Pine beetles	*Tomicus pini*	–	1	1	– – –
Pine leaf miner	*Paralechia pinifoliella*	–	1	1	– – –
Pine leaf scale	*Chionaspis pinifoliæ*	7	–	7	Chestnut Hill, Hamilton, Greenfield, Millbury, Plainfield, Springfield, Wellesley.
Pine webbers	*Benta* sp.	2	–	2	Boston, Framingham.
Pine web worm	*Benta melanogrammos*	1	–	1	Boston.
Pink boll worm	*Pectinophora gossypiella.*	1	–	1	Albany, N. Y.
Plant lice	Aphididæ	29	5	34	Arlington (2), Ashburnham, Beverly, Billerica, Brookline, Chatham, Conway, Danvers, Essex, Fairview, Groton, Haverhill, Hinsdale, Holliston, Hyde Park, Lenox, Leominster, Lowell, Melrose (2), North Andover, Pocasset, West Roxbury, West Somerville, Worcester, Belgrade Lake, Me., Basking Ridge, N. J., Readsboro, Vt.
Plum curculio	*Conotrachelus nenuphar.*	4	–	4	Belmont, Groveland, Williamstown, Woods Hole.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis.			Reported from —
		Letter.	Phone.	Total.	
Polyphemus moth	*Telea polyphemus*	1	–	1	North Conway, N. H.
Poplar borer	*Cryptorhynchus lapathi*	2	–	2	Dorchester, Farnumsville.
Potato and cornstalk borer.	*Papaipema nitela*	7	–	7	Boston, Edgartown (2), Groton Mansfield, Medford Hillside, Turners Falls.
Potato flea beetles	– –	–	1	1	– – –
Potato leaf hopper	*Empoasca mali*	2	1	3	Boston, Madison, Wis.
Potato lice	*Macrosiphum solanifolii.*	1	1	2	Lowell.
Poultry pests	– –	1	–	1	Lexington.
Powder post beetles	*Lyctus* sp.	1	–	1	Dorchester.
Promethea moth	*Callosamia promethea*	1	–	1	Boston.
Psocids	Psocidæ	1	–	1	West Newbury.
Purple-backed cabbage worm.	*Evergestis straminalis*	2	–	2	Athol, Watertown.
Railroad worm	*Rhagoletis pomonella*	1	–	1	Holliston.
Raspberry cane borer	*Oberea bimaculata*	4	–	4	Brookline, Lynn, Salem, Winchendon.
Rats	– –	7	1	8	Blandford, Brockton, Boylston, North Dana, Orange, Petersham, Whitman.
Red bugs	– –	–	1	1	– – –
Red spider	Acarina	1	–	1	Yakima, Wash.
Red squirrels	– –	1	–	1	Essex.
Root borers	– –	–	1	1	– – –
Root maggots	– –	1	1	2	Dorchester.
Rose chafer	*Macrodactylus subspinosus.*	2	1	3	Lenox, Rockport.
Rose curculio	*Rhodites bicolor*	1	–	1	Rockport.
Rose pests (greenhouse).	– –	–	1	1	– – –
Rose scale	*Aulacaspis rosæ*	1	–	1	Mansfield.
San José scale	*Aspidiotus perniciosus*	1	–	1	Greenfield.
Sawflies	*Dolerus collaris*	1	–	1	Boston.
Sawfly larvæ	Tenthredinidæ	1	–	1	Northfield.
Scales	Coccidæ	4	1	5	Palmer, South Braintree, Wakefield, Worcester.
Screw worm fly	*Chrysomyia macellaria*	1	–	1	Dallas, Tex.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Scurfy scale	*Chionaspis furfura*	3	–	3	Boston, Rockport, Boyertown, Pa.
Seed maggots	– –	–	1	1	– – –
Seed corn maggot	*Hylemyia cilicrura*	1	2	3	Milton.
Serpentine park miner	*Marmara* sp.	1	–	1	Northborough.
Sesiid injury	*Sesia pyri*	–	1	1	– – –
Shot hole borer	*Ecoptogaster rugulosus*	1	–	1	Norwood.
Silk worms	*Bombyx mori*	2	–	2	Wareham (2).
Silver fish	*Lepisma saccharina*	4	–	4	Boston (2), Framingham, Greenfield.
Slug caterpillars	Limacodidæ	1	–	1	Dunstable.
Snout beetle	Rhynchophora	1	–	1	Pepperell.
Soft scales	Coccidæ	7	1	8	Greenfield, Lincoln, New Bedford, Rockland, Sterling, Whitman (2).
Sooty fungus (following insect injury).	– –	–	1	1	– – –
Sow bugs	Oniscidæ	2	–	2	East Bridgewater (2).
Sphinx moth	Sphingidæ	2	–	2	Bolton, South Boston.
Spiders	Arachnida	2	–	2	Lunenburg, Worcester.
Spotted garden slug	*Limax* sp.	1	–	1	Fitchburg.
Spruce gall louse	*Chermes abietis*	1	–	1	Pittsfield.
Squash bug	*Anasa tristis*	7	7	14	Dorchester, Mattapoisett, Reading, Rock, South Gardner, Springfield, Stoneham.
Squash vine borer	*Melittia satyriniformis*	25	4	29	Boston, Bradford, Cambridge, Dedham, Fall River, Framingham, Holliston, New Bedford, Reading, Rockland, Southborough, Spencer, Stoneham, Stoughton, Warren, Wayland, West Springfield (2), Weymouth, Whitman, Worcester (5).
Strawberry insect	– –	1	–	1	Albany, N. Y.
Strawberry pests	– –	–	1	1	– – –
Strawberry root worm	*Paria canellus*	1	–	1	Doylestown, Pa.
Stripped cucumber beetle.	*Diabrotica vittata*	14	1	15	Arlington, Attleboro Falls, Boston, Fall River, Framingham, Holliston, Hyde Park, Mattapoisett, Raynham Center, Rockland, Southborough, Stoneham, Wayland, Worcester.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Sugar maple borer	*Plagionotus speciosus*	1	–	1	Chesterfield.
Syrphid fly	Syrphidæ	1	–	1	Amherst.
Tabanid fly	*Tabanus* sp.	1	–	1	Wellesley Farms.
Tarnished plant bug	*Lygus pratensis*	3	1	4	Boston, Hubbardston, Templeton.
Tent caterpillar	*Malacosoma americana*	1	1	2	South Boston.
Termites	Termitidæ	1	2	3	Pocasset.
Terrapin scale	*Lecanium nigrofasciatum.*	4	2	6	Holyoke (2), Northampton, Pittsburg, Pa.
Thrips	Thysanoptera	1	–	1	East Whately.
Thread-waisted wasps	Sphecoidea	1	–	1	Barnard, Vt.
Three-lined potato beetle.	*Lema 3-lineata*	1	–	1	New Bedford.
Thysbe moth	*Hemaris thysbe*	1	–	1	Bridgewater.
Tiger triton	Amphibia	1	–	1	Greenfield.
Tomato worm	*Phlegethontius 5-maculata.*	2	–	2	Cliftondale, Rockland.
Tree hopper	Membracidæ	4	–	4	Grafton, Medway, Springfield, Taunton.
Trumpet grape gall	*Vitis viticola*	1	–	1	Amherst.
Trumpet leaf miner	*Tischeria malifoliella*	2	–	2	Ipswich, Maynard.
Tulip tree scale	*Toumeyella liriodendri*	1	–	1	Westfield.
Two-spotted lady beetle.	*Adalia bimaculata*	1	–	1	Needham.
Walking stick	Phasmidæ	1	–	1	Wrentham.
White flies	Aleyrodidæ	2	2	4	Springfield, Worcester.
White grub	*Lachnosterna* sp.	8	1	9	Amherst, Concord (2), Hudson, Melrose, Shrewsbury, Springfield, West Newbury.
White-marked tussock moth.	*Hemerocampa leucostigma.*	2	–	2	Maynard, Springfield.
White pine weevil	*Pissodes strobi*	2	–	2	Holliston, Silver Lake P. O.
Wireworms	Elateridæ	3	1	4	Medfield, Plymouth, Randolph.
Willow insects	– –	1	–	1	North Truro.
Woolly apple aphis	*Schizoneura lanigera*	6	2	8	Boston, Longmeadow, Northampton, Wakefield, Woburn (2).
Zebra caterpillar	*Mamestra picta*	1	–	1	South Duxbury.
– –	*Aegeria* sp.	1	–	1	Brooklyn, N. Y.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Concluded.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis.			Reported from —
		Letter.	Phone.	Total.	
- -	*Anomala lucicola*	1	-	1	South Lincoln.
- -	*Apanteles congregatus*	1	-	1	Waltham.
- -	*Basilarchia archippus*	-	3	3	- - -
- -	*Carabus auratus*	2	-	2	Melrose Highlands, Winchester.
- -	Hymenoptera	1	-	1	Washington, D. C.
- -	Lepidoptera	1	-	1	Miniota, Man.
Totals		616	222	838	

The Crop Disease Situation in 1921.

Department of Botany,
Prof. A. V. Osmun, Head.

About the usual number of plant diseases was reported during the year. Six hundred and thirty-nine diagnoses, representing 166 different diseases, were made by the department in response to requests for assistance. However, the season was rather free from serious outbreaks of disease, only three assuming the importance of epidemics.

Weather conditions are a very large controlling factor in the occurrence and prevalence of plant diseases. In general, periods of heavy precipitation and high humidity during the growing season favor outbreaks of disease. This, however, by no means applies to all plant diseases.

The season of 1921 opened with an unusually warm and wet spring which advanced vegetation fully a week beyond normal. The longest period of rainfall of the entire year, extending over seven days, from April 27 to May 3, provided conditions ideal for the discharge and germination of the ascospores of the apple scab fungus, *Venturia inaequalis,* with consequent abundant scab infection of the apple. The most serious outbreak of apple scab in years resulted, and certain varieties, notably McIntosh, were severely infected, especially where effective spraying was not practiced. A second period of heavy rainfall, accompanied by high temperatures and humidity, occurred in July. During this period there was much secondary scab infection on both fruit and leaves. Had not the apple crop been greatly reduced by a killing frost on May 12, to which further reference will be made, the loss from scab doubtless would have been enormous. This opinion is supported by records of observation in many orchards where a small amount of fruit survived the freeze, and the McIntosh showed from 90 to 100 per cent infection.

The fruit crops were severely damaged by heavy frosts on April 19 and 20 and on May 12. The first freeze injured cherries and plums in the bud, especially in the western part of the State. The damage, however, was not total, resulting only in thinning of the buds; and had not the May 12 freeze, which was general throughout the State, completed the damage, doubtless a good crop of cherries and plums would have been harvested.

Peaches suffered to some extent, but their protective covering of woolly hairs seems to have prevented serious injury from the frosts, and many varieties produced a good crop of fruit.

The damage to apples caused by the low temperatures of April 19 and 20 was not apparent until the opening of the fruit buds about ten days later, when it was observed that many of the buds had been partially injured as indicated by a variety of abnormalities, mostly due to killing of part of the petals and stamens. Few of the buds showing such injury developed normal fruit. The May freeze, which occurred after the petal drop, proved much more disastrous to the apple, killing the newly set fruit outright. From 75 to 90 per cent of the fruit set on Baldwin and McIntosh was ruined. Early varieties, such as Wealthy, Yellow Transparent and Gravenstein, did not suffer to any great extent, probably due to their more advanced development. The damage was greatest in the eastern section of the State.

Tobacco wildfire, caused by *Bacterium tobacum*, was first observed in Massachusetts in 1920, but only three cases were reported. In the spring of 1921 a general epidemic of the disease occurred in the seed-beds of the Connecticut valley, causing widespread concern among tobacco growers. From the seed-beds the disease was carried to the field, where in many instances it spread with alarming rapidity. No attempt has been made to estimate the loss from this disease, but fields in which infection of the plants was practically total were not uncommon. Naturally, the value of such a crop is very greatly reduced, if indeed the grower is able to find a market for it. Although there has been no thorough study of the relation of weather conditions to occurrence and spread of wildfire, it is known that moisture favors its development, and that rain contributes to its dissemination in the field. It therefore seems probable that the abnormally wet weather of April and May was of major importance in the outbreak and development of the disease in seed-beds, and that the frequent showers and high humidity were to a large degree responsible for its spread and development in the field.

The third disease to appear in epidemic form was the downy mildew of cucumber and melon caused by *Pseudoperonospora cubensis*. This disease is favored by warm, humid and rainy weather occurring after the first of June. It causes no appreciable injury in dry summers. The earliest recorded seasonal date of its appearance in Massachusetts is May 1, 1915. In 1921 it was first noted early in June, when it appeared on cucumbers both in greenhouses and out of doors. From that time, favored by weather conditions of late June and July, it spread and developed rapidly. The resultant damage to the cucumber crop was very heavy, for following the initial outbreak vines were killed and new growth was very generally checked, thus effectively preventing setting and development of new fruit. In a few houses, where Bordeaux mixture was applied under the direction of the department, the disease was held in check and paying crops were harvested. Judging from this year's results it is probable that spraying for cucumber mildew under glass will prove profitable in years when the disease appears. As the spraying was in no instance started until after the mildew appeared on the vines, it seems likely that a preventive spray, that is, one applied prior to occurrence of the disease, will not be necessary, thus eliminating the necessity of spraying in years of no mildew.

The season was further notable for the almost complete absence of potato late blight which so often proves disastrous to the crop in years when wet weather occurs in August and September. The condition is explained by the fact that the rainfall and humidity both of these months and of October were considerably below normal.

Diagnosis of Plant Diseases.

A statement of the kind and character of the plant diseasès for which diagnostic service was requested during the year follows: —

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921.

[Figures in parentheses indicate the number of diagnoses of the same diseases in a town; where there is no figure only one diagnosis was made.]

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Almond	Brown-rot	*Sclerotinia* sp.	1	Woburn.
Apple	Bitter pit	Physiological	5	Amherst, Colrain, Goshen, Haydenville, Reading.
	Bitter-rot	*Glomerella rufomaculans* Berk.	2	Amherst, Concord.
	Black-rot	*Physalospora cydoniae* Arn.	18	Amherst (3), Annisquam, Brookfield, Groton (2), Littleton (4), Pittsfield, Rowley, Southborough, West Acton, Westborough, Whitman.
	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	3	Amherst, North Truro, Sunderland.
	Canker	*Physalospora cydoniae* Arn.	8	Amherst (4), Littleton, Lunenburg, South Deerfield, West Acton.
	Canker, bark	*Myxosporium corticolum* Edg.	3	Littleton (3).
	Canker, European	*Nectria cinnabarina* (Tode) Fr.	3	Amherst, Groton, Lunenburg.
	Canker, nail-head	*Nummularia discreta* (Schw.) Tul.	1	Lunenburg.
	Crown-gall	*Pseudomonas tumefaciens* E. F. Smith & Townsend.	2	Athol, Littleton.
	Fire-blight	*Bacillus amylovorus* (Burr.) De Toni	3	Amherst, Westfield, Woods Hole.
	Fruit-spot	*Phoma pomi* Pass.	6	Amherst, Colrain, Greenfield, Haydenville, Littleton, Shelburne, Wareham.
	Frost injury to blossom and fruit.	— — —	12	Amherst, Fitchburg, Groton (2), Haydenville, Littleton (6), West Acton.
	Leaf-spot	*Coniothyrium pirina* (Sacc.) Shel.	1	Pittsfield.
	Leaf-spot	*Physalospora cydoniae* Arn.	5	Amherst (3), Groton (2).
	Rust	*Gymnosporangium macropus* Link	3	Amherst, Taunton, Woods Hole.

	Scab	*Venturia inaequalis* (Cke.) Wint.	61	Amesbury, Amherst (4), Annisquam, Arlington, Ashland, Beverly, Boston, Bridgewater, Brockton, Concord Junction (3), Essex, Falmouth, Fitchburg (4), Groton (6), Hadley, Harvard (5), Holliston, Kendal Green, Littleton (16), Lunenburg, Melrose Highlands, Oxford, Salisbury, South Dennis, Vineyard Haven, Waltham, Watertown, West Acton (2).
	Sooty blotch and fly speck	*Leptothyrium pomi* (Mont. & Fr.) Sacc.	5	Amherst (3), Haydenville, Sunderland.
	Spongy dry-rot	*Volutella fructi* Stevens & Hall	2	Amherst, Boston.
	Sun-scald	Physiological	3	Lunenburg, Rowley, Touisset.
	Winter injury	– – –	2	Amherst, Groton.
Ash	Disease not determined	– – –	1	Topsfield.
	Rust	*Puccinia fraxinata* (Link) Arthur	2	Ipswich, Wareham.
Asparagus	Crown-rot	*Fusarium* sp.	7	Amherst (2), Arlington, Concord, Lexington, Littleton (2).
	Rust	*Puccinia asparagi* DC.	5	Amherst (2), Lexington, Littleton, Sunderland.
Aster	Dry stem-rot	*Fusarium* sp.	4	Amherst, Boston, Cambridge, North Wilmington.
	Root-rot	*Rhizoctonia* sp.	1	Amherst.
	Yellows	Physiological	3	Amherst, Foxborough, West Brookfield.
Barberry	Rust	*Puccinia graminis* Pers.	3	Amherst, Belchertown, Leverett.
Barley	Smut	*Ustilago Hordei* (Pers.) Kel. & Sw.	1	Amherst.
	Smut	*Ustilago nuda* (Jens) Kel. & Sw.	1	Amherst.
Bean	Anthracnose	*Colletotrichum lindemuthianum* (Sacc. & Magn.) B. & C.	8	Amherst (6), Arlington, West Millbury.
	Blight	*Pseudomonas phaseoli* Erw. Smith	3	Amherst (2), Arlington.
	Rust	*Uromyces appendiculatus* (Pers.) Link	2	Arlington, Manchester.
	Stem and root-rot	*Rhizoctonia* sp. and *Fusarium* sp.	5	Amherst (4), Lexington.

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Continued.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Beet	Leaf-spot	*Cercospora beticola* Sacc.	2	Amherst, Lexington.
Blackberry	Anthracnose	*Gloesporium venetum* Speg.	2	Amherst, Littleton.
	Crown-gall	*Pseudomonas tumefaciens* E. F. Smith & Townsend.	1	Amherst.
	Leaf-spot	*Septoria rubi* Westd.	1	Amherst.
	Rust	*Gymnoconia peckiana* (Howe) Tranz	1	Northampton.
Cabbage	Brown-rot	*Pseudomonas campestris* (Pammel) Erw. Smith	1	Arlington.
	Clubroot	*Plasmodiophora brassicae* Wor.	3	Amherst, Gardner, Great Barrington.
	Disease not determined	- - -	4	Pittsfield (4).
	Leaf-spot	*Alternaria brassicae* (Berk.) Sacc.	2	Arlington, Lexington.
	Soft-rot	*Bacillus carotovorus* Jones	1	Amherst.
Carnation	Root-rot	*Rhizoctonia solani* Kühn.	2	Amherst, Northborough.
	Rust	*Uromyces Caryophyllinus* (Schrank) Wint.	1	Amherst.
	Wilt	*Fusarium* sp.	3	Amherst, Manchester, Northborough.
Carrot	Blight	*Macrosporium* sp.	3	Amherst, Lexington, Marblehead.
	Soft-rot	*Bacillus carotovorus* Jones	3	Amherst, Lexington, Marblehead.
Catalpa	Leaf-spot	*Phyllosticta catalpae* Ell. & Mart.	1	Holyoke.
Cedar	Rust	*Gymnosporangium macropus* Link	1	Woods Hole.

Celery	Crown-rot	*Bacillus carotovorus* Jones	2	Amherst, Lexington.
	Early-blight	*Cercospora apii* Fr.	2	Amherst, West Springfield.
	Late-blight	*Septoria Petroselini* Desm. var. *Apii* Br. & Cav.	5	Amherst, Arlington, Lexington, West Springfield, Worcester.
Cherry	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	2	Amherst, Worcester.
	Leaf-spot	*Coccomyces hiemalis* Higgins	3	Amherst (3).
Chestnut	Canker	*Endothia parasitica* (Murrill) A. & A.	7	Amherst (2), Goshen, Granby, Prescott, South Deerfield, Sunderland.
	Disease not determined	- - -	1	Horse Shoe, N. C.
Chrysanthemum	Black spot	*Cylindrosporium Chrysanthemi* Ell. & Dearn.	1	Amherst.
Corn	Rust	*Puccinia Sorghi* Schw.	2	Amherst (2).
	Smut	*Ustilago Zeae* (Beckm.) Ung.	3	Amherst (3).
Cucumber	Downy mildew	*Pseudoperonospora cubensis* (B. & C.) Rostew.	12	Amherst (4), Arlington (4), Deerfield, Harvard, Lexington, Sunderland.
	Root-knot	Nematode worms	2	Amherst, Arlington.
	Stem-rot	*Sclerotinia Libertiana* Fckl.	4	Amherst, Arlington (3).
	White pickle or mosaic	Physiological	4	Medford (2), South Deerfield, South Hadley.
	Wilt	*Bacillus tracheiphilus* Erw. Smith	1	South Hadley.
Currant	Anthracnose	*Pseudopeziza Ribis* Kleb.	3	Amherst, Millis, Rowley.
	Rust	*Aecidium Grossulariae* Schum.	1	Haverhill.
Eggplant	Rot	*Botrytis fascicularis* (Cda.) Sacc.	2	Amherst, Braintree.
	Wilt	*Verticillium* sp.	3	Amherst, Braintree, Lexington.
Elm	Heart-rot	*Polyporus sulphureus* Fr.	1	Northampton.
	Leaf-spot	*Dothidella ulmea* (Schw.) Ell. & Ev.	3	Amherst, Groton, Ludlow.
	- - -	Saprophytic polypori	1	Holyoke.

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Continued.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Gladiola	Bulb-rot	Cause undetermined	1	Longmeadow.
Grape	Anthracnose	*Gloeosporium ampelophagum* Sacc.	1	Boston.
	Black-rot	*Guignardia Bidwellii* (Ell.) Viala & Ravaz.	8	Amherst, Boston, Farnumsville, Lunenburg, Millbury (2), Princeton, Randolph.
Grass (lawn)	– – –	*Rhizoctonia* sp.	4	Amherst (2), Newburyport, Pittsfield.
Hawthorn	Leaf-blight	*Entomosporium thumenii* (Cke.) Sacc.	3	Norton, Segreganset, Worcester.
	Rust	*Gymnosporium clavariaeforme* (Jacq.) Rees.	2	Cambridge, Taunton.
Hollyhock	Rust	*Puccinia malvacearum* Mont.	7	Amherst, Hyannis, Rowe, South Dartmouth, Still River, West Medway, West Newton.
Horsechestnut	Leaf-blight	*Guignardi aesculi* (Pk.) Stew.	2	Amherst, Williamstown.
Iris	Root-rot	*Bacillus carotovorus* Jones	1	Amherst.
Ivy	Leaf-spot	*Guignardi Bidwellii* (Ell.) V. & R.	1	Marion.
Lettuce	Bottom-rot	*Rhizoctonia solani* Kühn.	3	Amherst, Arlington (2).
	Drop	*Sclerotinia Libertiana*	16	Arlington (12), Belmont, Lexington, Watertown, West Springfield.
	Gray mold	*Botrytis cinerea* Pers.	4	Arlington (3), Belmont.
	Root-knot	Nematode worms	2	Amherst, Arlington.
Lilac	– – –	Frost injury	1	Groton.
Linden	Leaf-spot	*Gloeosporium* sp.	1	Amherst.
Maple	Black spot	*Rhytisma acerinum* (Pers.) Fr.	3	Amherst (2), Pittsfield.
	Leaf-spot	*Phyllosticta* sp.	1	Pittsfield.
	Sun-scald	Physiological	3	Holyoke, Palmer (2).

Melon	Anthracnose	*Colletotrichum lagenarium* (Pers.) Ell. & Halst.	1	Woods Hole.
Oak	Leaf-spot	*Vermicularia* sp.	1	Pittsfield.
Oats	Crown-rust	*Puccinia coronata* Cda.	1	Manchester.
	Leaf-blight	*Helminthosporium inconspicum* (C. & Ell.)	1	Dalton.
	Smut	*Ustilago Avenae* (Pers.) Jens.	3	Amherst, Goshen, Greenfield.
Onion	Damping-off	*Pythium de Baryanum* and *Fusarium* sp.	4	Amherst, Leverett, Sunderland (2).
	Leaf-spot	*Macrosporium* sp.	2	Sunderland (2).
	Neck-rot	*Botrytis* sp.	8	Amherst (2), Hadley, Hatfield, Sunderland (4).
	Smudge	*Vermicularia circinans* Berk.	1	Amherst.
	Smut	*Urocystis cepulae* Frost	14	Amherst (3), Atkinson, N. H., Leverett, North Hadley, South Deerfield (2), Sunderland (6).
Parsnip	Soft-rot	*Bacillus carotovorus* Jones	2	Amherst (2).
Pea	Root-rot	*Fusarium* sp.	7	Amherst (4), Brockton, Hingham, Rockland.
Peach	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	5	Amherst, East Taunton, Hingham, Manchester, Squantum.
	Canker and gummosis	*Sclerotinia cinerea* (Pers.) Schroet.	4	Amherst (2), Groton, Littleton.
	Leaf-curl	*Exoascus deformans* (Berk.) Fckl.	3	Amherst, Milton, Woods Hole.
	Scab	*Clodosporium carpophilum* Thüm.	1	East Taunton.
Pear	Crown-gall	*Pseudomonas tumefaciens* Erw. Smith & Townsend.	1	Boston.
	Fire-blight	*Bacillus amylovorus* (Burr.) De Toni	2	Amherst (2).
	Scab	*Venturia Pyrina* Aderh.	3	Amherst, Provincetown, Quincy.
	Tip-burn	Physiological	1	Cambridge.
Peony	Stem-rot	*Botrytis Poeoniae* Oud.	1	Touisset.

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Continued.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Phlox	Powdery mildew	*Erysiphe cichoracearum* DC.	2	Amherst, Canaan, N. H.
Pine	Disease undetermined	– – –	1	Medford.
	Sun-scald	Physiological	6	Amherst, East Northfield, Greenfield, Shelburne, South Hadley, Sunderland.
Plum	Black knot	*Plowrightia morbosa* (Schw.) Sacc.	4	Amherst, Cliftondale, Lincoln, South Weymouth.
	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	4	Amherst (2), Arlington, Littleton.
	Leaf-spot	*Coccomyces Prunophoroe* Higgins	2	Amherst (2).
Popcorn	Ruptured kernel	Probably due to crossing with field corn	1	Walpole.
Poplar	Canker	*Dothichiza populea* S. & B.	2	Boston (2).
Potato	Black heart	Physiological	3	Amherst, New Salem, Worcester.
	Early-blight	*Macrosporium solani* E. & M.	2	Amherst (2).
	Hollow heart	Physiological	2	Amherst, Brighton.
	Late blight	*Phytopththora infestans* (Mont.) deBary	2	Amherst (2).
	Leaf-roll	Physiological	5	Amherst (2), Cummington, Goshen, Sunderland.
	Mosaic	Physiological	6	Amherst (4), Cummington, Goshen.
	Scab	*Actinomyces chromogenus* Gasperini	2	Amherst, Falmouth Heights.
	Scurf or Rhizoctonia	*Corticium vagum* B. & C. var. *Solani* Burt	3	Amherst (2), Sunderland.
	Soft-rot	*Bacillus* sp.	2	Amherst (2).
	Tip-burn	Physiological	7	Amherst (3), Hadley (2), Holliston, Sunderland.

Quince	Rust	*Gymnosporium clavipes* C. & P.	5	Amherst, Boston, Granby, Hadley, Montague.
Raspberry	Anthracnose	*Gloeosporium venetum* Speg.	2	Athol, Hudson.
	Cane-blight	*Coniothyrium Fuckelii* Sacc.	1	Boston.
	Crown-gall	*Pseudomonas tumefaciens* Erw. Smith & Townsend.	2	Haverhill, Westdale.
	Leaf-spot	*Septoria Rubi* West	1	Enfield.
	Spur-blight	*Mycosphoerella rubina* (Pk.) Jacz.	2	West Acton, Haverhill.
	Yellows	Physiological	2	Amherst, Plymouth.
Rose	Black spot	*Actinonema Rosae* Wolf	2	Hadley, Willimantic, Conn.
	Crown-gall	*Pseudomonas tumefaciens* Erw. Smith & Townsend.	2	Hadley, Boston.
	Powdery mildew	*Sphaeortheca pannosa* (Wallr.) Lev.	4	Amherst, Gloucester, Groveland, Holden.
Snapdragon	Rust	*Puccinia antirrhini* D. & H.	1	Northampton.
	Wilt	*Verticillium* sp.	1	Northampton.
Spinach	Disease undetermined	– – –	3	Arlington, Lexington, Worcester.
Squash	Black mold	*Mucor mucedo* L.	1	Amherst.
	Downy mildew	*Pseudoplasmopora cubensis* B. & C.	1	Harvard.
Strawberry	Fruit-rot	*Rhizopus nigricans* Ehr.	1	Amherst.
	Gray mold	*Botrytis* sp.	1	Amherst.
	Leaf-spot	*Mycosphaerella fragariae* (Tul.) Lin.	4	Amherst, Montague, North Wilmington, Standish.
	Root-rot	Undetermined	3	Amherst, Caryville, Montague.
Sweet pea	Bud drop	Physiological	2	Amherst, Arlington.
Sycamore	Anthracnose	*Gnomonia Veneta* (Sacc. & Speg.) Kleb.	2	Amherst (2).

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Concluded.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Tobacco	Damping-off	*Pythium de Baryanum* Hesse.	5	Hatfield, North Hadley, Southwick, Sunderland, Westfield.
	Mosaic	Physiological	2	South Deerfield (2).
	Root-rot	*Thielavia basicola* (B. & Br.) Zopf.	4	Hatfield, North Hatfield, South Deerfield, Sunderland.
	Wildfire	*Bacterium tobacum* Wolf & Foster	88	Agawam, Amherst (2), Congamond (2), Conway, Deerfield (6), Feeding Hills, Hadley (3), Hatfield (8), Haydenville, Hillsborough (2), North Amherst (3), North Hadley (7), Northfield, North Sunderland, South Deerfield (7), Southwick (11), Sunderland (6), Westfield, West Hatfield, West Suffield, Conn., West Whately (3), Whately (19).
Tomato	Anthracnose	*Colletotrichum Phomoides* (Sacc.) Chester	1	Amherst.
	Blossom end rot	Physiological	2	Amherst, Arlington.
	Early-blight	*Macrosporium solani* Ell. & Mart.	1	Amherst.
	Leaf-spot	*Septoria Lycopersici* Speg.	1	Amherst.
	Mosaic	Physiological	2	Amherst, West Springfield.
	Root-galls	Nematode worms	2	Amherst, Arlington.
	Wilt	*Fusarium* sp.	1	Arlington.
	Winter-blight	Bacterial	3	Amherst, Arlington, Berlin.
Turnip	Black-rot	*Pseudomonas campestris* (Pam.) E. F. Sm.	1	Millers Falls.
	Clubroot	*Plasmodiophora brassicae* Wor.	1	Amherst.
	Disease undetermined	- - -	1	Millers Falls.

Violet	Root-knot	Nematode worms	1	Amherst.
Walnut (black)	Disease undetermined	– – –	1	South Deerfield.
Wisteria	Sun-scald	Physiological	1	Rowe.
Total			639	

METEOROLOGICAL OBSERVATIONS.

DEPARTMENT OF METEOROLOGY,

PROF. J. E. OSTRANDER, HEAD.

Annual Summary for 1921.

Pressure (in Inches).

Maximum reduced to freezing	30.56, Jan. 19, 10 A.M.
Minimum reduced to freezing	29.03, Oct. 20, 3 P.M.
Maximum reduced to freezing and sea level	30.90, Jan. 19, 10 A.M.
Minimum reduced to freezing and sea level	29.33, Oct. 20, 3 P.M.
Mean semi-daily reduced to freezing and sea level	30.040
Annual range	1.57

Air Temperature (in Degrees Fahr.).[1]

Highest	96.0, June 22, 3 P.M.
Lowest	—6.0, Jan. 19, 7 A.M.
Mean hourly	49.5
Mean of means of maximum and minimum	49.8
Mean sensible (wet bulb)	44.4
Annual range	102.0
Highest mean daily	80.6, July 8
Lowest mean daily	4.0, Jan. 19
Mean maximum	60.5
Mean minimum	39.0
Mean daily range	21.5
Greatest daily range	48.5, Oct. 15
Least daily range	3.0, Nov. 19

Humidity.

Mean dew point	40.4
Mean force of vapor	405
Mean relative humidity	76.0

Wind.

Prevailing direction	W. S. W.

[1] Temperature in ground shelter.

Summary.

South southwest	22 per cent
North	10 per cent
Northwest	10 per cent
Other directions	58 per cent
Total movement	52,373 m.
Greatest daily movement	465 m., Jan. 25
Least daily movement	13 m., July 4
Mean daily movement	143 m.
Mean hourly velocity	6.0 m.

Maximum pressure per square foot, 29.0 lbs., = 76 m. per hour, Dec. 18, 5 A.M. W.S.W.

Maximum velocity for 5 minutes, 36 m. per hour, Nov. 5, 7 A.M. N.W.; Dec. 18, 7 A.M. W.S.W.

Precipitation (in Inches).

Total precipitation, rain or melted snow	42.22
Snow total in inches	37.5
Number of days on which .01 or more rain or melted snow fell	131

Weather.

Mean cloudiness observed	50 per cent
Total cloudiness recorded by sun thermometer	1,819 hrs. = 40 per cent.
Number of clear days	126
Number of fair days	141
Number of cloudy days	98

Bright Sunshine.

Number of hours recorded	2,695 hrs. = 60 per cent

Dates of Frosts.

Last	May 12
First	Oct. 9

Dates of Snow.

Last	April 18
First	Nov. 7
Total days of sleighing	28

Gales of 50 or More Miles Per Hour.

Mar. 29, 50m., N.; Nov. 5, 61m., N.W.; Dec. 3, 54m., W.N.W.; Dec. 18, 76m., W.S.W.

REPORT OF THE TREASURER.

FRED C. KENNEY.

United States Appropriations, 1920–21.

		Hatch Fund.	Adams Fund.
Dr.			
To receipts from the Treasurer of the United States, as per appropriations for the fiscal year ended June 30, 1921, under acts of Congress approved March 2, 1887, and March 16, 1906,		$15,000 00	$15,000 00
Cr.			
Adams:			
By salaries	$14,171 24		
labor	512 82		
seeds, plants and sundry supplies	98 88		
fertilizer	142 48		
feeding stuffs	8 45		
scientific apparatus and specimens	66 13		
	$15,000 00		15,000 00
Hatch: —			
By salaries	$14,902 50		
labor	97 50	15,000 00	
	$15,000 00		

State Appropriations, 1920–21.

Cash balance brought forward from last fiscal year	–
Cash received from State Treasurer	$76,430 03
fees	15,095 88
sales	10,128 13
miscellaneous	343 56
	$101,997 60

Cash paid for salaries	$41,957 85
labor	17,115 23
publications	1,327 74
postage and stationery	2,017 22
freight and express	266 50
heat, light, water and power	525 08
chemicals and laboratory supplies	1,388 81
seeds, plants and sundry supplies	2,688 64
fertilizer	1,079 18
feeding stuffs	1,611 83
library	691 98
tools, machinery and appliances	952 09
furniture and fixtures	112 45
scientific apparatus and specimens	269 83
live stock	1,143 00
traveling expenses	2,346 35
contingent expenses	30 00
buildings and land	906 25
Remitted to State Treasurer	25,567 57
Total	$101,997 60

BULLETIN No. 201.

DEPARTMENTS OF CHEMISTRY, ENTOMOLOGY, AND BOTANY.

INSECTICIDES AND FUNGICIDES FOR FARM AND ORCHARD CROPS IN MASSACHUSETTS.

BY E. B. HOLLAND, A. I. BOURNE AND P. J. ANDERSON.

The successful production of farm and orchard crops depends in large measure on the protection afforded against injurious insects and bacterial and fungous diseases. Obviously there is no remedy — that is, no panacea for all noxious insects and parasitic diseases of plant life — that would not also destroy the host. The method of treatment, therefore, must be essentially specific, and for convenience will be divided into three major groups: (A) Insecticides, (B) Fungicides, and (C) Combined applications.

A. INSECTICIDES.

The injurious insects that infest the crops under consideration are of two distinct types as determined by their mode of feeding: *i.e.*, biting and sucking. The former type consumes organized tissue, and the latter draws sustenance from plant juices. The respective treatment of the two types is necessarily different and warrants a division of insecticides into (I) Stomach poisons for biting insects, and (II) Contact poisons for sucking insects. The stomach poisons of to-day owe their origin largely to the Colorado potato beetle, and the contact poisons to the San José scale.

The acknowledged requisites for an insecticide are —

1. Non-toxicity as to plant.
2. Effectiveness in destroying the insect.
3. Adhesiveness or persistence under all weather conditions.
4. Fineness of particles and a light flocculent character (when insoluble) to insure a high power of suspension and uniform distribution.
5. Ability to indicate the surface covered.
6. Reasonable cost.

The factors that facilitate distribution naturally differ somewhat in soluble and insoluble products, dust and spray applications. These attributes comprise a standard for judging insecticides, and apply in principle to fungicides as well.

I. STOMACH POISONS FOR BITING INSECTS.

Nearly all stomach poisons of the present time are compounds of arsenic, and this has led to the general use of the term "arsenicals" for this group of insecticides. Very little work has been done, and still less has been published, in regard to the exact nature of the toxic action of arsenic on the physical structure of insects. The fact that this action takes place and the rapidity of its killing effect upon the insects in question have been practically the only points to which writers have hitherto given their attention.

The sprays consist of minute particles of the poison, suspended in the water or other vehicle, which are deposited upon the food of the insect and adhere to it upon drying.

1. Arsenicals.

There are two forms of arsenicals to be considered: —

1. The lower or arsenous oxide, or arsenic trioxide (white arsenic) (As_2O_3).
2. The higher or arsenic oxide, or pentoxide (As_2O_5).

When these two oxides are combined with bases, the former yields the so-called (*a*) Arsenites, and the latter (*b*) Arsenates.

Arsenites as a class are noticeably more active poisons than the arsenates, but are relatively unstable and more likely to cause injury to the plant, and for that reason they have been largely supplanted.

Depending on the form in which the arsenic may be present, arsenicals are sold on a guaranty in which the amount of arsenic (the active principle) may be stated in the following terms: —

Percentage of arsenous oxide or arsenic trioxide (As_2O_3) or white arsenic.
Percentage of arsenic pentoxide (As_2O_5).
Percentage of elemental arsenic (metallic arsenic).

The first form is used in guaranties of Paris green, whereas either the second or third form is used in stating guaranties of arsenates. Notwithstanding the fact that the killing power of arsenates and arsenites varies in rapidity, and possibly in final extent, the percentage of metallic arsenic seems to be the only common denominator by which to compare one arsenical with another.

(*a*) Arsenites.

A number of arsenites have been placed on the market at one time or another. Paris, Schweinfurt, or Emerald green, a well-known poisonous pigment, was first used about 1868 (1).[1] This date, therefore, marks the

[1] Numbers in parentheses indicate literature cited, which will be found on pages 35–37.

beginning of the era in which active agents supersede the old-time repellents (2), which were usually characterized by offensive (both odor and taste) or caustic rather than poisonous properties. Some, however, may have possessed value as contact poisons. In 1875 Scheele's green (3) was introduced, in 1877 London purple (4), and in 1891 calcium arsenite (5).

There are several other commercial products which are worthy of mention, although many of them contain soluble arsenic, and in some cases uncombined white arsenic may have been a constituent. Gray arsenoid was a mixture of calcium and copper arsenites. Barium arsenite or white arsenoid was essentially a mixture of barium compounds and of arsenic rather than a true salt. Zinc arsenite was employed by potato growers in certain localities for a few seasons. Laurel green was a mixture of copper arsenite, gypsum and green sand. Paragrene was a mixture of Paris green and gypsum.

Paris green, because of its quick action and comparative safeness when applied with lime, still maintains a place in the list of recommended arsenicals, but has certainly lost much of its former prominence.

(1) *Paris Green.*

Composition. — Paris green is a copper aceto-arsenite for which the formula of Eugene Ehrmann is generally accepted: —

$$(CH_3COO)_2\,Cu.3Cu\,(AsO_2)_2$$

As a double salt it may be said to consist of 1 part of copper acetate and 3 parts of copper metarsenite. The composition of the theoretical salt is as follows: —

		Per Cent.
Cupric oxide (CuO),		31.385
Arsenous oxide (As_2O_3),		58.550
Equivalent to metallic arsenic (As) (per cent),	44.350	
Ratio CuO : As_2O_3,	1 : 1.866	
Acetic anhydride $(CH_3CO)_2O$,		10.065
		100.000

Stability. — While Paris green is nominally insoluble in water, it is in reality unstable, and breaks down under continuous percolation of water, with the liberation of soluble and hence injurious arsenic. Carbonic acid, ammonia and certain alkaline salts likewise tend to increase the solubility of the arsenic. Since conditions which control the presence of these substances cannot always be foretold, it is always well to add milk of lime to Paris green to prevent arsenical injury. It does this by uniting with the free and loosely combined arsenic to form calcium arsenite, which is insoluble and hence non-injurious to the foliage.

Form of Guaranty. — The form of guaranty under which Paris green is sold is as follows: —

	Per Cent.
Total arsenous oxide, not less than	50.00
Water soluble arsenous oxide, not more than	3.50

The statement of total arsenous oxide in the above guaranty may be taken as representing the effectiveness of the material in terms of the killing principle which it contains. The statement of soluble arsenous oxide indicates the maximum amount of injurious compounds of arsenic.

The above guaranty corresponds to the Federal standard. Paris green as offered for sale in this State fully meets this guaranty.

To summarize: Paris green is of high arsenic content, and that in the form of arsenous oxide, nominally insoluble in water, but unstable, hydrolyzing readily, and likely to cause injury unless applied with lime. It is an active poison with a low power of suspension, but admitting of reasonable distribution; a poor indicator without lime of the leaf surface covered; and of fair adhesiveness and persistence under average weather conditions.

(*b*) **Arsenates.**

As a group arsenates are rapidly supplanting arsenites, because they have greater stability and are less likely to injure foliage. Of the five arsenates which at one time or another have been used in practice or have been sold in commerce, lead arsenate, developed in 1894 (6), is unquestionably the most satisfactory. Calcium arsenate, first manufactured about 1912,[1] is serviceable, but has a more limited field of usefulness. Magnesium arsenate has been on the market for but two seasons, while the arsenates of zinc and iron are of but minor importance.

(1) *Lead Arsenate.*

F. C. Moulton (7), chemist for the Massachusetts Gypsy Moth Commission, was the first to prepare arsenate of lead for insecticide purposes in 1892. The work was continued by F. J. Smith (8), who studied various matters pertaining to the manufacture, and stated that ordinary spray material was not a single salt, but a mixture of neutral and acid arsenates. Lead arsenate paste appears to have been first prepared commercially about 1895 by the Merrimac Chemical Company of Boston, under the trade name of Swift's arsenate of lead. Disparene, manufactured by the Bowker Insecticide Company of Boston, followed soon after. Dry lead arsenate (Electro) was prepared as an insecticide by the Vreeland Chemical Manufacturing Company of New York about 1909. The California Experiment Station mentioned a dry product in 1903, but gave no information as to its source. Dry, *bulky* acid lead arsenate was first prepared in 1912 by the Corona Chemical Company of Milwaukee, Wis.

There appear to be three different lead arsenate salts, as follows: —

1. Acid lead arsenate, $PbHAsO_4$. This is the lead arsenate ordinarily sold in New England.
2. Neutral lead arsenate, $Pb_3(AsO_4)_2$.
3. Basic lead arsenate (9), $Pb_5OH(AsO_4)_3$.

[1] Correspondence from manufacturers on file.

A few writers claim that pyroarsenate, $Pb_2As_2O_7$, may occur in commercial products, but the evidence at hand does not support the assertion.

Composition. — The composition of theoretical acid, neutral and basic lead arsenates is as follows: —

	Acid Lead Arsenate (Per Cent).		Neutral Lead Arsenate (Per Cent).		Basic Lead Arsenate (Per Cent).	
Lead oxide (PbO), ...		64.291		74.440		75.924
Arsenic pentoxide (As_2O_5), . . .		33.114		25.560		23.463
Equivalent to metallic arsenic (As) (per cent).	21.590		16.667		15.299	
Ratio As_2O_5 : PbO, ...	1 : 1.942		1 : 2.912		1 : 3.236	
Water of combination, ...		2.595		0.000		0.613
		100.000		100.000		100.000

From the above table it is evident that the acid lead arsenate as it is sold in New England is considerably more concentrated than is either the neutral lead arsenate or the basic lead arsenate. From economic standpoints alone this matter is of importance.

Physical Properties. — These products, whether acid or mixed acid and neutral arsenates, are usually smooth white pastes of finely divided, amorphous particles, less than 1 μ in size, with a good power of suspension and exceptional adhesiveness. The so-called neutral salt has almost invariably been a mixture of acid and neutral, and very little has been marketed. The physical structure of the neutral salt, or of mixtures containing considerable neutral lead arsenate, is rather inferior to that of the acid salt, and the basic material used in southern California is said to be relatively coarse and granular. The power of suspension is injured by drying or freezing. These pastes are compact and "greasy," but fairly miscible with water when properly handled. The acid salt is less compact, has a lower specific gravity and higher power of suspension, and is a more active poison than the neutral or basic. The specific gravity of the acid salt (amorphous form) (10) at 15/15° C. is 5.93, the neutral (10), 7.32, and the basic (11), at 20/4° C., 7.105.

More recently the dry powders have displaced the pastes in large measure at a material saving in cost of containers, transportation, possible leakage and danger of injury on storage. This product is a white, bulky (fluffy) powder of fine amorphous particles, with a very high power of suspension and excellent adhesiveness. The "old type" dry acid arsenate ran about 40 cubic inches to the pound, and the "new type" 70 to 80 cubic inches. The neutral and basic products are more dense, but actual figures are not available, as they are seldom if ever marketed in dry form. The product, as offered in Massachusetts markets, is essentially the acid arsenate. It is more readily miscible with water than the paste, and a time saver in this respect.

Stability. — Acid and neutral lead arsenates are practically insoluble in cold water, but continuous percolation may cause decomposition. Hot water is more effective, but may cause slight hydrolysis, particularly of the acid salt. Dilute solutions of sodium carbonate, sodium chloride and sodium sulfate have been shown (12, 13) to increase the solubility of the arsenic, especially where the common acid lead arsenate is used. Stability may be obtained by adding calcium hydroxide (milk of lime) to acid or neutral arsenate. The former will necessarily require more base to afford like protection. The basic salt sold in the West contains only about 20 to 22 per cent of arsenic pentoxide on a dry basis.

Form of Guaranty. — The usual form of guaranty under which dry lead arsenate is sold is substantially as follows: —

		Per Cent.
Active ingredients: —		
Lead arsenate, not less than		98.00
Total arsenic pentoxide, not less than	31.00	
Total arsenic (as metallic), not less than	20.20	
Inert ingredients, not more than		2.00
		100.00
Water Soluble.		
Soluble arsenic pentoxide, not more than		0.75
Soluble arsenic (as metallic), not more than		0.50

As in the case of Paris green, an article is desired which contains a high percentage of total arsenic with a low maximum percentage of soluble arsenic. It is well to note further that in the above guaranty the essential statements are those italicized. The other statements made simply repeat this information in different form.

The Federal standard (14) for commercial lead arsenate specifies not more than 50 per cent of water, nor less than 12.50 per cent of total arsenic pentoxide (equivalent to 8.15 per cent metallic arsenic), and not more than 0.75 per cent of arsenic pentoxide soluble in water (equivalent to 0.49 per cent metallic arsenic).

To maintain a high standard of purity the product, whether paste or powder, should be substantially free from carbonate, chloride, sulfate and acid soluble matter, and should not contain more than 2.50 per cent, on a dry basis, of water soluble by-products. The dry acid lead arsenate sold in the East is usually guaranteed to contain 30 or 31 per cent of total arsenic pentoxide (equivalent to 19.56 or 20.21 per cent metallic arsenic), and not more than 0.75 or 1 per cent of arsenic pentoxide soluble in water (equivalent to 0.49 or 0.65 per cent metallic arsenic). The paste is usually guaranteed to contain 15 per cent arsenic pentoxide (equivalent to 9.78 per cent metallic arsenic), and not more than 0.75 per cent arsenic pentoxide soluble in water.

To summarize: Lead arsenate is of low arsenic content, and that in the form of pentoxide, practically insoluble in water, fairly stable under New England weather conditions, and may be applied to most plants with little danger of injury. It is a slow-acting poison but effective; the fineness of particles and light flocculent character insure a high power of suspension and uniform distribution; the white mixture readily indicates the leaf surface covered, and dries to a film which adheres with great persistence.

(2) *Calcium Arsenate.*

Arsenate of lime was employed as an insecticide about 1912, or possibly earlier. Dry arsenate of lime appears to have been first prepared commercially by Riches, Piver & Co. of New York. The late war, with resulting high prices, brought the product into prominence.

As with lead arsenate there are three separate products to be considered, as follows: —

1. Acid calcium arsenate, $CaHAsO_4H_2O$.
2. Neutral calcium arsenate, $Ca_3(AsO_4)_22H_2O$.
3. Basic calcium arsenate, a product of rather variable composition, probably depending on the amount of excess lime. This is the commercial article sold under the name of calcium arsenate.

Composition. — The composition of theoretical acid and neutral calcium arsenates, and of a commercial basic calcium arsenate, is substantially as follows: —

	Acid Calcium Arsenate (Per Cent).	Neutral Calcium Arsenate (Per Cent).	Commercial Basic Calcium Arsenate (Per Cent).
Calcium oxide (CaO),	28.310	38.744	44.128
Arsenic pentoxide (As_2O_5),	58.045	52.957	45.238
Equivalent to metallic arsenic (As) (per cent).	37.848	34.531	29.497
Ratio As_2O_5 : CaO,	1 : 0.488	1 : 0.732	1 : 0.975
Water of combination,	13.645	8.299	10.634
	100.000	100.000	100.000

Physical Properties. — The calcium arsenates are soft, white powders of fine particles with a good power of suspension and adhesiveness. The specific gravity (15) of a pure acid salt at 20/4° C. was 3.09, and of a neutral salt, 3.23. The commercial dry basic calcium arsenate is a bulky, impalpable powder of 80 to 100 cubic inches to the pound.

Stability. — The acid salt is largely soluble in water, and the neutral salt appreciably so, as determined by the Hilgard method. Carbonic acid will decompose both salts with the formation of carbonate and the liberation of arsenic. Dilute solution of alkalies and their salts will increase the solubility of the arsenic, the acid salt invariably proving the more unstable. For these several reasons calcium arsenate used alone burns foliage very badly. As in the case of other arsenicals, milk of lime prevents burning by combining with any soluble arsenic which may be formed.

The basic products are more stable than the acid or neutral salts, due evidently to the higher content of lime.

The status of the dry commercial products is still rather indefinite. Carbonate of lime is present in some instances as an impurity or filler, having neither toxic nor protective action.

Form of Guaranty. — Calcium arsenate is usually sold under the following form of guaranty: —

		Per Cent.
Active ingredients: —		
Tricalcium arsenate, not less than		76.00
Total arsenic pentoxide, not less than	42.50	
Total arsenic (as metallic), not less than	28.00	
Inert ingredients, not more than		24.00
		100.00
Water Soluble.		
Soluble arsenic pentoxide, not more than		1.50
Soluble arsenic (as metallic), not more than		1.00

The remarks relative to the form of guaranty of lead arsenate hold equally well for the form of guaranty of calcium arsenate. Note particularly that the killing power of calcium arsenate is apparently greater than that of lead arsenate on account of the higher percentage of arsenic pentoxide. Therefore a smaller quantity is used in the spray, so as to give the same amount of metallic arsenic as when arsenate of lead is used.

To summarize: Both acid and neutral calcium arsenates are of relatively high arsenic content, but too soluble to warrant their use without excess lime. The basic product is of a lower arsenic content but more stable. They are effective poisons, the fineness of particles and light flocculent character insuring a fair power of suspension and uniform distribution. The white mixture indicates the leaf surface covered, and dries to a film that is persistent under average weather conditions; and is, in brief, an efficient and reasonably satisfactory arsenical for the more resistant plants.

Standard Formulas for Application.

As previously mentioned, there is a great difference in the rapidity of killing power between arsenates and arsenites. For this reason the two classes of materials cannot be compared on the basis of arsenic contained. The following table represents basic quantities of the several materials of standard or near standard composition which may be used. Naturally the amounts to be used must be varied to adapt the spray to different kinds of insects, and to make it safe when used on different kinds of plants.

Arsenical.	Composition of Arsenical.		Amount of Arsenical in Spray.		Pounds of Metallic Arsenic per Barrel of Spray.
	Arsenic Oxides (Per Cent).	Equivalent in Metallic Arsenic (Per Cent).	Per Barrel (50 Gallons) (Pounds).	Per Gallon (Ounces).	
Arsenites: —					
Paris green, ...	50.00 (As_2O_3)	37.87	0.333	1/10	0.126
Arsenates: —					
Dry acid lead arsenate, .	30.00 (As_2O_5)	19.56	1.5	1/2	0.3—
Dry basic calcium arsenate,	40.00 (As_2O_5)	26.08	1.0	1/3	0.3—

Any arsenite of known composition may be applied in quantity to furnish metallic arsenic equal to that in an application of Paris green; whereas any arsenate of known composition may be applied to furnish metallic arsenic equivalent in amount to that used in arsenate of lead.

For most farm and orchard crops it is unwise to use any arsenical without protecting the plant against foliage damage. The addition of milk of lime affords protection against this arsenical injury. Four pounds of high-grade quicklime (95 per cent CaO) are generally sufficient for 50 gallons (1 barrel) of spray. The lime should be slaked carefully, sieved, diluted to nearly 50 gallons, and the arsenical added slowly with thorough agitation *immediately* before application.

Arsenical Injury.

It is evident from what has been stated repeatedly that the carbonic acid and ammonia of the atmosphere in conjunction with dews, fogs or light rains and high temperatures will materially increase the amount of soluble arsenic. When the arsenic is in solution in the spray liquid, or drops of rain or dew on the foliage, some of it is absorbed by the tissues of the leaf. A very minute amount of absorbed arsenic may have no injurious effect on the cell; but if, on account of a high soluble arsenic content of the spray material, or too long standing of the liquid before drying, a sufficient amount has been absorbed, the tissue is killed. Two types of injury are distinguished (16), — *acute* poisoning and *chronic* poisoning.

In cases of *acute poisoning* the leaf, or large areas of it, turns black within twenty-four hours after the application; or sometimes, when the insecticide has dried rapidly after application, the blackening may appear after the first period when water has stood on the foliage for some time. In *chronic poisoning* there are no definite lesions on the leaves, but after two or three weeks they prematurely turn yellow and drop off. Apparently in this type of poisoning not enough arsenic is absorbed to kill the cells outright, but yet enough to interfere with and finally stop the functioning of the cells.

Certain deductions seem warranted. Conditions favoring a rapid drying of the arsenical and its continuance in a dry state are propitious.

For instance, a relatively high temperature, low humidity and a good circulation of air at the time of application, followed by warm, dry weather should tend toward a minimum of arsenical injury. On the other hand, factors conducive to solubility of the arsenic and its passage by osmosis into the substance of the leaf are detrimental, as, for example, warm, "muggy" weather, or warm weather accompanied by fogs or heavy dews. Rains are not necessarily injurious if of sufficient quantity to wash off the soluble arsenic as soon as it is formed.

2. Hellebore.

White hellebore is the powdered rhizome (root) of *Veratrum album*, and green or American hellebore that of *V. viride*. Both are sold as insecticides in the form of a gray powder containing about 1 per cent of alkaloids (usually guaranteed from 0.30 to 0.42 per cent) and a varying amount of ash. Though known to possess poisonous properties, hellebore received little attention until about 1842 in England (17), and 1865 in this country (18).

The chief insecticidal action of hellebore is as a stomach poison. It appears to possess also a certain value as a repellent. The active principles which give hellebore its insecticidal value are certain alkaloids which are poisonous to insects, but in amounts usually recommended for use do not seriously affect man. These alkaloids are so volatile that the material soon loses its strength and efficiency, particularly if exposed to the air. Consequently a fresh product should always be demanded. Its non-poisonous effect on man renders hellebore a suitable material for the protection against chewing insects of fruits or vegetables that are about to ripen or are soon to be eaten. It is, however, limited to rather small-scale applications, the cost of the material prohibiting its use on large areas. The material may be applied either dry or as a spray. In dry form it is used either undiluted or mixed with five times its volume of flour or finely divided air-slaked lime. For liquid application its use at the rate of ½ ounce to 1 gallon of water is recommended.

II. CONTACT POISONS FOR SUCKING INSECTS.

Contact poisons include a large number of diversified compounds (solid, liquid and gaseous), and their effectiveness may depend upon more than one property. The compound may act in any of the following ways: —

1. Glue the insect down.
2. Attack the body, dissolving fat and even muscle, precipitating proteids, etc.
3. Act as a narcotic, paralyzant or anæsthetic.
4. Asphyxiate the insect by closing the breathing pores (spiracles or tracheæ), or, by saturating the body, prevent necessary aeration.

These indicate some of the possibilities, but the principal action and the contributory are generally difficult to define. These poisons are generally soluble or emulsified products. They kill only by contact. Liberal and thorough application is necessary to assure effectiveness, and drench spraying is usually employed. The weaker the surface tension of the spray and the thinner the chitin of the insect the more rapid the penetration.

The contact poisons that will be considered are (1) soaps, (2) sulfur sprays, (3) oil sprays, (4) nicotine, and (5) pyrethrum.

1. Soaps.

There are four different types of soap sprays, as follows: —

1. Whale-oil or fish-oil soaps.
2. Laundry soap.
3. Rosin fish-oil soap, soap "stickers."
4. Fish-oil soaps and nicotine.

(1) *Whale-oil or Fish-oil Soaps.*

Whale-oil soap was first brought forward in 1842 by the experiments of Haggerston (19), and showed an efficiency which it has steadily maintained up to the present. It is interesting to note that many of the statements made at that time in regard to its value have proved true through years of subsequent use, and the dosage first recommended is practically the same as that used to-day.

At the present time soaps made from fish oil have largely supplanted the true whale-oil soaps, but the similarity in the nature and effectiveness of the two materials has led to the habit of using these two names more or less interchangeably. Strictly speaking, however, the commercial product to-day is largely made from various fish oils.

For use as a summer spray against plant lice and other soft-bodied insects, as well as younger stages of more resistant types, it is very effective when applied at the rate of 1 pound to 6–8 gallons of water, according to the tenderness of the plant in question. It has sometimes been used for dormant treatment of scale insects at the rate of 2 pounds to 1 gallon of water, and applied while hot. The stronger, more efficient sulfur sprays have largely supplanted it for this purpose.

(2) *Laundry Soap.*

In the absence of whale-oil or fish-oil soaps, common laundry soap may be employed effectively for the same type of insects. An average soap of this type should be used at the rate of 1 pound to 2–4 gallons of water, depending on the resistance of the insects treated.

(3) *Rosin Fish-oil Soap, Soap "Stickers."*

On plants having a smooth and waxy foliage, such as cabbage and similar types, lead arsenate and Bordeaux mixture will not adhere at all well unless used with some kind of soap as a "sticker." Types of resinous soaps have come into use under the general name "Resin (Rosin) Fish Oil Soaps," and are especially adapted for such purposes. These are recommended to be used at the rate of 3–4 pounds to 50 gallons of spray (or about 1 ounce to 1 gallon), and to be added to the diluted spray material immediately before it is to be applied. In the preparation of this type of soap for a spray it is necessary to add the water a little at a time, stirring vigorously all the while, until the soap has entirely dissolved; otherwise the resinous nature of the material repels the water, making a solution almost impossible.

Except on the particular types of plants just mentioned (cabbage and similar plants), soap should not be used with arsenicals or Bordeaux mixture. Arsenicals are unstable in the presence of the alkali of the soap, with the consequent danger of the formation of soluble arsenic (20). In this particular case, however, the application is made so soon after the soap is added that there is little opportunity for breakdown; and, further, the waxy leaves seem to offer more resistance to arsenical injury than would foliage of ordinary texture. The alkalies entering into the composition of our common soaps are mainly compounds of sodium and potassium. Such soaps are the only ones soluble in water. When, however, soap is combined with Bordeaux mixture or lime-sulfur sprays, calcium soaps are formed which are insoluble in water, making a gummy, sticky mass which is apt to clog the spray apparatus. Moreover, other products of this breakdown are formed which are either actively dangerous to the plant or are of no use whatever as an insecticide.

(4) *Fish-oil Soaps and Nicotine.*

Commercial brands of fish-oil soaps combined with a small amount of nicotine are on the market and appear to have a considerable sale. These are rather expensive, and usually their nicotine content is quite low, so that in general, better satisfaction can be obtained by combining soap and nicotine solutions as needed. (See Nicotine Sprays, page 20.)

2. Sulfur Sprays.

These are efficient contact poisons for certain scale insects, and possess substantial fungicidal value as well. They are supplanting the miscible oils, probably due in large measure to the deleterious after-effects of the latter. Concentrated lime-sulfur solution, dry lime-sulfur, barium tetrasulfide (B. T. S.), and sodium polysulfide, or so-called soluble sulfur, will be considered. All of these materials seem to have the following properties in common: —

1. The amount of polysulfide sulfur present largely governs the effectiveness of the material.

2. Thiosulfate sulfur is a product of the breaking down of polysulfide as well as an original constituent of the product, and hence is present in variable amounts.

3. The free sulfur contained is usually inert as an insecticide. It does, however, have a distinct fungicidal value. (See page 26.)

(1) *Lime-sulfur.*

The efficiency of lime-sulfur-salt wash (21) for the San José scale appears to have been first demonstrated by F. Dusey of Fresno, Cal., in 1886, using a sheep dip prepared by A. T. Covell. The dip (22, 23), however, seems to have been of Australian origin. About the year 1900 it began to be used in the eastern States for the control of the San José scale.

The formulas adopted by different experiment stations showed appreciable variations. A proportion of 1 pound of lime and 2–2¼ pounds of sulfur to 1–1⅝ gallons of water assures solution of the largest proportions of lime and sulfur, the smallest amount of sludge or sediment, and a high proportion of calcium polysulfide (particularly pentasulfide) with a moderate amount of calcium thiosulfate, thus making the most efficient product with the least waste. The lime must be a high-grade caustic, substantially free from magnesia, which causes unnecessary loss of sulfur as hydrogen sulfide and increases the amount of sediment. A greater proportion of lime causes the formation of more thiosulfate, and favors the formation of crystals of oxysulfide. Boiling for thirty to sixty minutes with proper agitation should be sufficient to dissolve all of the sulfur; longer heating is detrimental. The resulting solution should be about 24° or 25° Baumé. A greater concentration is generally obtained at a sacrifice of thiosulfate, which is converted into sulfite and free sulfur which being insoluble increase the amount of sediment.

The commercial product has largely superseded the home-made except, possibly, in the case of orchard practice on a large scale. Lime-sulfur solution appears to have been first produced commercially by the Rex Spray Company (formerly Rex Stock Food Company) of Omaha, Neb., as a sheep and cattle dip, which was approved by the Bureau of Animal Industry Sept. 30, 1903. Later the product was tested as a spray at Corvallis, Ore., and largely marketed as such. The commercial concentrate is to-day practically standardized on a 33° Baumé basis. A product of greater density is more likely to crystallize on chilling.

Concentrated lime-sulfur properly prepared is a clear orange-red solution with more or less sludge, depending on the purity of the lime and sulfur, formula, and method of treatment. The clear solution consists chiefly of so-called calcium polysulfide and calcium thiosulfate in varying amounts. The sludge may contain free sulfur, together with calcium sulfite, calcium sulfate and impurities from the lime. The polysulfide is a combination of lime and sulfur, approximating a ratio of 1 : 5, or CaS_5; the thiosulfate is CaS_2O_3.

Composition. — A comparison of home-made concentrate and the commercial 33° Baumé concentrate is shown in the following table: —

	Home-made (24½° B) (Per Cent).		Commercial (33° B) (Per Cent).	
Water,		75.00		68.04
Sulfur in solution,		17.00		24.75[1]
Polysulfide sulfur,	13.75		24.00	
Thiosulfate sulfur,	3.25		.75	
Ratio thiosulfate sulfur to polysulfide sulfur,	1 : 4.23		1 : 32.00	
Calcium,		5.57		6.65
Oxygen in combination,		2.43		.56
		100.00		100.00
Water,	75.00		68.04	
Calcium polysulfide ($CaS_{4.85}$)	17.29		30.18	
Calcium thiosulfate,	7.71		1.78	
	100.00		100.00	

[1] A conservative estimate.

Stability. — Lime-sulfur is readily oxidized on exposure to air, the polysulfide being converted into thiosulfate with precipitation of sulfur, the thiosulfate into sulfite with precipitation of additional sulfur, and the sulfite into sulfate, as follows: —

$$CaS_5 + O_3 = CaS_2O_3 + S_3$$
$$CaS_2O_3 = CaSO_3 + S$$
$$CaSO_3 + O = CaSO_4$$

This necessitates full containers, well-stoppered, or a thin covering of paraffin oil to prevent decomposition of lime-sulfur in storage.

The guaranty of commercial concentrates is generally about 33° Baumé and 25 per cent sulfur in solution. The efficiency, however, is more accurately measured by the amount of polysulfide sulfur in solution, irrespective of whether the effectiveness is a result of direct action or from products of decomposition. The total sulfur in solution apparently gives the home-made product, containing a much larger proportion of thiosulfate sulfur, relatively too high a rating.

According to P. J. Parrott, of the New York (Geneva) Agricultural Experiment Station, a gallon of diluted lime-sulfur for dormant spray (San José scale) should contain about 0.297 pound of sulfur in solution, or 3.45 per cent; and for fungicidal work on foliage, 0.065 pound of sulfur, or 0.775 per cent. The following formulas are so calculated for concentrates of 15° to 36° Baumé: —

TABLE I. — *Standard Formula for Application (24).*

Density of Solution, Baumé Degrees.	Equivalent in Specific Gravity.	Sulfur Equal to 1° B. (Per Cent).	Weight of 1 Gallon of Concentrate (Pounds).	Sulfur in 1 Gallon of Concentrate (Pounds).	Sulfur in Solution (Per Cent).	Dilution for San José Scale:[1] To 1 Gallon of Concentrate add Gallons of Water.	**Dilution for San José Scale:[1] For 50 Gallons of Spray use Gallons of Concentrate.**	Dilution for Summer Spray:[2] To 1 Gallon of Concentrate add Gallons of Water.	**Dilution for Summer Spray:[2] For 50 Gallons of Spray use Gallons of Concentrate.**
36	1.3303	0.75	11.08	2.99	27.00	9	**5**	45	**1**
35	1.3182	.75	10.98	2.88	26.25	8¾	**5¼**	43¼	**1¼**
34	1.3063	.75	10.88	2.77	25.50	8¼	**5¼**	41½	**1¼**
33	**1.2946**	**.75**	**10.78**	**2.67**	**24.75**	**8**	**5½**	**40**	**1¼**
32	1.2832	.74	10.69	2.53	23.70	7½	**5¾**	37¾	**1¼**
31	1.2719	.74	10.60	2.43	22.95	7¼	**6**	36¼	**1¼**
30	1.2609	.73	10.51	2.30	21.90	6¾	**6½**	34¼	**1½**
29	1.2500	.73	10.42	2.20	21.15	6½	**6¾**	32¾	**1½**
28	1.2393	.72	10.32	2.08	20.15	6	**7¼**	31	**1½**
27	1.2288	.72	10.23	1.99	19.45	5¾	**7½**	29½	**1½**
26	1.2185	.71	10.15	1.87	18.45	5¼	**8**	27¾	**1¾**
25	1.2083	.70	10.07	1.76	17.50	5	**8½**	26	**1¾**
24	1.1983	.69	9.98	1.65	16.65	4½	**9**	24¼	**2**
23	1.1885	.68	9.90	1.55	15.65	4¼	**9½**	22¾	**2**
22	1.1789	.67	9.82	1.45	14.75	3¾	**10¼**	21¼	**2¼**
21	1.1694	.66	9.74	1.35	13.85	3½	**11**	19¾	**2½**
20	1.1600	.65	9.67	1.26	13.00	3¼	**11¾**	18¼	**2½**
19	1.1508	.65	9.59	1.18	12.35	3	**12½**	17	**2¾**
18	1.1417	.65	9.51	1.11	11.70	2¾	**13½**	16	**3**
17	1.1328	.65	9.44	1.04	11.05	2½	**14¼**	15	**3¼**
16	1.1240	.65	9.37	0.97	10.40	2¼	**15¼**	14	**3¼**
15	1.1154	.65	9.30	0.90	9.75	2	**16½**	12¾	**3½**

[1] Density of spray, 4.6° Baumé, or 1.0327 specific gravity.
[2] Density of spray, 1.0° Baumé, or 1.0072 specific gravity.

(2) *Dry Lime-sulfur.*

Dry lime-sulfur was first marketed in 1915 by the Sherwin-Williams Company of Cleveland, Ohio. The use of the dry product effects a material saving in cost of containers, transportation, storage and possible leakage. Commercial lime-sulfur solution contains nearly 68 per cent of water, while the dry product usually contains only a small amount of uncombined water. In the production of dry lime-sulfur the polysulfide apparently undergoes partial decomposition, and a portion of the sulfur formerly combined with the lime splits off and fails to redissolve on the addition of water, and is termed free sulfur.

Composition. — Dry lime-sulfur is usually guaranteed about as follows: —

		Per Cent.
Active ingredients,		80.00
Calcium polysulfide,	63.00	
Calcium thiosulfate,	5.00	
Free sulfur,	12.00	
Inert ingredients,		20.00
		100.00

A 33° Baumé lime-sulfur solution containing 24.75 per cent sulfur, concentrated to a like basis, should contain substantially 61.95 per cent total sulfur. If 12 per cent was rendered insoluble by evaporation, 49.95 per cent remains soluble. Five per cent calcium thiosulfate is equivalent to 2.11 per cent thiosulfate sulfur, which deducted from the soluble sulfur leaves 47.84 per cent polysulfide sulfur.

(3) *Barium Tetrasulfide.*

Barium tetrasulfide (25) or B. T. S. was prepared experimentally as an insecticide by the Thomsen Chemical Company of Baltimore, Md., in 1913. The product is guaranteed as follows: —

		Per Cent.
Active ingredients,		82.00
Barium tetrasulfide (BaS_4),	68.00	
Barium thiosulfate,	6.00	
Free sulfur,	8.00	
Inert ingredients,		18.00
		100.00

Barium tetrasulfide is a fairly satisfactory contact poison, yet it possesses no distinct advantages over lime-sulfur preparations. It has never replaced lime-sulfur to any great extent, and is not now widely used, largely because it is more expensive.

(4) *Soluble Sulfur.*

Soluble sulfur or sodium polysulfide was first marketed by the Niagara Sprayer Company of Middleport, N. Y., about 1912. Con-sol, a sodium sulfur compound, prepared by the American Horticultural Distributing Company of Martinsburg, W. Va., was offered about 1905, but little information has been received relative to the nature of the product.

Soluble sulfur is guaranteed as follows: —

		Per Cent.
Active ingredients,		85.00
Sodium polysulfide (Na_2S_4),	56.00	
Sodium thiosulfate,	25.00	
Free sulfur,	4.00	
Inert ingredients,		15.00
		100.00

Soluble sulfur is used considerably as a dormant spray, and is fairly satisfactory. It is exceedingly dangerous as a foliage spray unless an excess of lime is added. It has no marked superiority over lime-sulfur preparations, and has not supplanted them to any great degree.

Formulas for Application.

These various materials may all of them be applied in such quantities as to furnish approximately equivalent amounts of soluble sulfur. That this basis is not entirely sound is shown by the fact of difference in the ratio between polysulfide sulfur and thiosulfate sulfur. This difference should, of course, be considered when computing amounts of spray materials needed. On the basis of amounts of soluble sulfur equal to the standard application of 33° Baumé lime-sulfur concentrate (1–8 for dormant spray and 1–40 for summer spray), the following table is presented as showing suggested formulas for application: —

Material.	Soluble Sulfur (Per Cent).	Amount of Material in 50 Gallons of —			
		Dormant Spray.		Summer Spray.	
		Gallons.	Pounds.	Gallons.	Pounds.
Lime-sulfur concentrate,	24.75	5.556	59¾	1.22	13
Dry lime-sulfur,	50.00	–	29½[1]	–	6½
Barium tetrasulfide,	41.00	–	36[1]	–	8
Soluble sulfur,	51.35	–	28¾[1]	–[2]	–[2]

[1] These amounts are greater than are recommended by the manufacturers.

[2] Soluble sulfur should never be used as a summer spray, save with a great excess of lime.

3. Oil Sprays.

Oil sprays owe their insecticidal value chiefly to their asphyxiating effect. To a certain degree some of them may also have corrosive effect. Oil sprays likewise have a peculiar creeping power which enables the operator to cover the tree area even under unfavorable conditions. With most other contact insecticides, an insect to be killed must be actually "hit." These oils will be considered under two divisions: (1) emulsions, and (2) miscible oils.

(1) *Emulsions.*

The idea of combining soap, kerosene and water to form a stable mixture which could be safely applied to foliage undoubtedly occurred to growers very early. The first record of successful accomplishment, however, was in 1870 (26). Cook (27) records the attaining of a successful emulsion in experiments in 1877–78, and the formulas which he developed, bearing his name, were used for many years. The experiments of Riley and Hubbard, covering a number of years, carried forward this idea of a permanent mixture of kerosene and soap, and finally led to the production of the formula (28) which is used practically unchanged at the present day. This formula is as follows: —

Kerosene,	2 gallons
Water (soft),	1 gallon
Soap,	½ pound

The soap is dissolved in boiling water, and while the mixture is still hot the kerosene is added. The mixture is then churned, with a bucket pump with nozzle turned back into the liquid, until it has reached the consistency of a thick cream. Upon cooling, this thickens still further, and if properly made no free oil should separate out on the surface. This stock emulsion should last for some time, but it is much better to make it up only as needed. Where the water is hard it must be softened by the addition of borax or soda to prevent the lime or magnesium present from combining with the soap, which makes impossible an emulsion with the oil.

For spraying, dilute with 9–10 parts of water for aphids or other soft-bodied insects. Greater strengths are sometimes recommended for more resistant insects, or on trees when dormant.

Kerosene emulsion cannot be used safely in combination with other sprays (lead arsenate, lime-sulfur, etc.) owing to the breakdown of these materials in the presence of the soap, and the consequent liberation of free oil as well as other products of this double decomposition, which are dangerous to plants. This spray has now been largely superseded by the various nicotine solutions which have proved fully as efficient, are more easily prepared, can be used with safety to foliage, and, moreover, can be used in combination with other sprays, thus saving the trouble and expense of separate applications.

Carbolic Acid Emulsion. — This is a fairly effective remedy for certain root-feeding insects, such as root maggots of onion, cabbage and turnip. Its value for other purposes is somewhat limited. It is made as follows: —

Soap,	1 pound
Water,	1 gallon
Crude carbolic acid,	1 pint

This is prepared in the same way as is kerosene emulsion. It will not, however, attain the same curd-like consistency on standing as will kerosene emulsion, but remains in a more or less fluid condition. It should be diluted 1 part to 25–30 of water, and applied to the ground around the stems. Its use is restricted to small areas.

(2) *Miscible Oils.*

Miscible oils are formed from a mineral oil emulsified with a vegetable oil, with some alkali present. A stable stock emulsion is formed which mixes readily with water. These preparations are particularly adapted for use on old, rough-barked trees heavily encrusted with scale, as the oils spread over the bark more readily than do sulfur sprays. As the proportion of component parts is seldom furnished, and the manufacture of these oils is, in fact, more or less of a trade secret, the directions furnished by the manufacturer, both as to dilution and application, should be very carefully followed, whatever brand is used. In general, for dormant spraying these oils are diluted at the rate of 1 part to 12–15 parts of water.

The use of these oils has sometimes been followed by distinct injury, even where proper precautions have been taken and directions carefully followed. There are also reports of cumulative injury following repeated applications (29).

Miscible oils are relatively expensive dormant sprays in spite of the fact that the oil is said to go further in application than an equal amount of lime-sulfur. The uncertainty of the exact effect of the oils upon the health of the tree seems to favor the use of lime-sulfur, which has proved to be an efficient scale destroyer and can be used with safety.

4. Nicotine.

The value of tobacco in killing soft-bodied types of insects was discovered very early. In 1763 it was recommended in France for the control of plant lice, both tobacco powder and a water solution being applied. Its use in America was first recorded in 1814. Its effectiveness against soft-bodied insects and its safety to foliage of plants soon gave it a prominence which has continued undiminished to the present day. The most active principle of tobacco, and the one which gives it its value as an insecticide, is the alkaloid, nicotine. Soluble in water, entirely volatile, this is one of the most virulent poisons known.

(1) *Nicotine Sulfate.*

At the present time there are on the market a number of different commercial brands of nicotine, of various grades and strengths, which have to a large extent superseded the home-made preparations for general use. For garden and orchard operations the highly concentrated product containing 40 per cent of nicotine in the form of nicotine sulfate is at present extensively used. This is sold under various trade names, as "Black-Leaf 40," "Nicotine Sulfate 40%," etc. It has proved especially valuable for the control of many soft-bodied sucking insects. It can be applied at strengths required for efficient insect control without injury to foliage, and, moreover, it can be combined with other standard sprays (lime-sulfur, lead arsenate, etc.) without impairing either their efficiency or its own.

The amount of dilution recommended varies according to the resistance of the insects for the control of which it is applied. When used at a dilution of $\frac{3}{8}$–$\frac{1}{2}$ pint in 50 gallons of water (or, where only a few plants are to be treated, 1–1$\frac{1}{2}$ teaspoonfuls to 1 gallon of water), nicotine sulfate is efficient for the control of the average soft-bodied sucking insects of orchard and garden. When nicotine sprays are used alone in water, the addition of soap, 2–4 pounds to every 50 gallons of spray ($\frac{2}{3}$–1 ounce to 1 gallon), increases their spreading power and general effectiveness. Without soap the nicotine solutions show a tendency to form into drops which roll off the leaves without penetrating to and thoroughly wetting the insects. When nicotine sprays are used in combination with other insecticides the soap should *never* be added, owing to the breakdown of these chemicals in the presence of the strong alkali of the soap, with the consequent formation of compounds dangerous to foliage. (See page 12.)

Recent studies upon the effects of nicotine as an insecticide (30) have shown that, regardless of the form in which it is employed, the killing action is by paralysis, through the penetration of the nicotine vapors into the body of the insect. The effectiveness of nicotine sprays, therefore, depends on the amount of nicotine released. The experiments of Graham and Moore (31) have indicated that nicotine sulfate alone is nonvolatile, but if a solution of this material is treated with soap to render it alkaline, nicotine is at once released. Inasmuch, therefore, as the vapor of nicotine is the principal cause of the death of insects sprayed with tobacco solutions, the maximum efficiency of solutions containing nicotine sulfate can only be obtained by insuring that the spray is rendered alkaline. This is best attained by the addition of soap.

Within the last few years nicotine sulfate has been used, with lime and kaolin as carriers, in a dust application for the control of the walnut aphis and various truck crop insect pests, in California. In this form it has demonstrated a killing efficiency and rapidity of action superior to the spray applications. Furthermore, it can be applied faster and costs less than when applied in liquid form. So far as known, this has not as yet been used in Massachusetts. Its convenience of application and rather remarkable success as far as tried make it a promising form of application, especially in market gardens.

5. Pyrethrum.

Pyrethrum, Persian or Dalmatian insect powder, is the powdered flowers of *Chrysanthemum cinerariæfolium;* and Buhach, the California product, the powdered flowers of *C. coccineum*. The bright yellow powder owes its insecticidal value to the presence of certain volatile oils, contained in the flower heads, which are quite poisonous to insects, but apparently harmless to man. The material rapidly loses its effectiveness unless carefully stored in tight receptacles.

Pyrethrum is quite effective on soft-bodied insects and larvæ not protected by hairs, and is especially useful against young cabbage worms on cabbage and cauliflower plants which are soon to be harvested. It acts purely as a contact insecticide; the application must be made very thoroughly, therefore, to bring the material in actual contact with the insects to be treated. Its action is of short duration, the active principles being so volatile, and if used too sparingly some of the insects are merely numbed and eventually recover. Its usefulness is consequently very limited. It is rather costly, and is apt to vary as to purity.

Pyrethrum may be applied as a dry powder, pure or diluted with two to three times its bulk of flour, air-slaked lime, etc., which increases its adhesiveness. When diluted with any carrier it is well to keep the mixture in some tightly closed receptacle for twenty-four hours before using. It can also be applied as a spray at the rate of 1 ounce to 2 gallons of water, which should stand for twenty-four hours before using. For immediate use a decoction can be made by extracting in a quart of boiling water for from five to ten minutes, then adding the rest of the water.

B. FUNGICIDES.

Fungicides, as the term is applied in this bulletin, are substances used to kill or prevent the growth of fungi. They are applied to the host as spray, dust or fumes. For the most part, they are used as preventives and not cures, and therefore should be applied before the fungus is present on the surface of the host plant. As such, they protect by forming a poison barrier through which the threatening fungus cannot penetrate. Sometimes, however, they are used to destroy a pathogen (parasitic organism which causes the disease) which is already present; *e.g.*, powdery mildews and potato tuber organisms, in which case they are called disinfectants. In respect to use, then, we distinguish the two groups of fungicides: (I) Protective sprays or dusts, and (II) Disinfectants. In some cases, however, the same substance may be used for both purposes.

A good fungicide must have the following qualifications: —

1. It must kill or inhibit the growth of the pathogen at the concentration used.
2. It must not seriously injure the host plant at this same concentration.
3. If used as a spray it must adhere tenaciously to the surface of the host.
4. If used as a protective spray it must be practically insoluble in water after it dries on the host, but still go very gradually into solution under the influence of atmospheric conditions, host or pathogen.
5. It must be reasonably low in cost, both of material and of labor of application.

Most of the fungicides which are in general use owe their effectiveness to the presence in some form of one of three elements, — copper, sulfur or mercury. Formaldehyde, effective on account of its reducing qualities, is an exception. On this basis we shall divide them for convenience of discussion, as follows: —

I. PROTECTIVE APPLICATIONS.

1. Copper Fungicides.

This group of fungicides owes its effectiveness to the action of dissolved copper on the fungus. *Copper sulfate* was perhaps the first to come into general use. Its use for disinfection of smutted grain seed was perfected during the eighteenth century, and it is still used for that purpose in Europe and Australia.

Numerous *copper ammonia washes* have also been used with more or less success, mostly for the diseases of ornamental plants. The best known and most widely used of these washes are Eau celeste (cuprammonium sulfate) and ammoniacal copper carbonate. Since none of them has come into general use for farm or orchard crops, they need not be discussed further at this time.

The most popular and most extensively used of all copper fungicides is Bordeaux mixture. Home-made Bordeaux and commercial Bordeaux preparations are discussed separately below. Other copper fungicides have not been used enough to warrant separate discussion at this time.

(1) *Bordeaux Mixture.*

A thick paste made by mixing slaked lime with copper sulfate and applied to the grapevines of southern France for the purpose of warding off pilfering vagrants was the origin of Bordeaux mixture. Millardet, a professor of botany at Bordeaux, observed that the vines which were so treated suffered less from the downy mildew (*Plasmopora viticola*), which had been introduced from America into France about 1878. He began investigations, the results of which were published from 1882–85, and gave to the world its most widely used fungicide. The whole science of protective spraying began with his work. Soon after the effectiveness of Bordeaux mixture in controlling grape mildew had been demonstrated it was used with equal success for potato mildew and black rot of grape. In 1887 it was introduced into the United States by the United States Department of Agriculture, and its use extended to other diseases, until by the end of the century it had come to be regarded almost as a panacea for all fungous diseases of plants.

Formulas. — Bordeaux mixture as now used is still made from lime, copper sulfate (blue vitriol or bluestone) and water, but many different formulas for the proportions of the three ingredients have been proposed and used with success for various diseases. For Massachusetts crops and conditions the "4–4–50 formula" (4 pounds copper sulfate, 4 pounds quicklime and 50 gallons of water) is preferred, except in the case of the late sprays for potatoes and the spray for celery and grapes. In the latter cases 5–5–50 is recommended. Other formulas sometimes employed are 3–3–50, 5–4–50 and 6–4–50.

Chemical and Physical Properties. — When the dissolved copper sulfate and milk of lime are poured together, a reaction takes place between them resulting in the formation of a voluminous, gelatinous colloidal precipitate which does not settle rapidly to the bottom, but remains evenly distributed throughout the liquid and begins to settle only after standing undisturbed for several hours. As seen under the microscope it is a mass of very thin precipitation membranes, each in the form of a minute closed bag. After a few hours the gelatinous precipitate gradually becomes crystalline, the copper salt then appearing in the form of blue sphærocrystals (32) which do not remain afloat but settle to the bottom. In the best mixtures these membranes are most fully and abundantly formed, and as a result they "stand up" longest. In poor mixtures they settle to the bottom quickly. The ability of the mixture to perfectly cover the surface of the plant and to adhere tenaciously is dependent on the thoroughness of development of these precipitation membranes. It is therefore customary to gauge the excellency of the mixture to no inconsiderable extent by the length of time required for the precipitate to settle. Since even the best of mixtures will begin to settle after a few hours, it is essential that, to get the best results, Bordeaux be applied when freshly prepared. In the 4–4–50 Bordeaux there is a considerable excess of lime (as calcium hydroxide). When the spray dries on the leaves, the membranes which are spread over the surface conform tightly to every irregularity, much as a piece of thin wet tissue paper does when dried on a flat surface, and are not washed away readily by rains or removed by winds or other agencies. Bordeaux mixture surpasses all other fungicides in its ability to adhere to the host. Copper, its only active fungicidal agent, is in these dry membranes in a form almost insoluble in pure water. Since it cannot affect the fungus in an insoluble form, it must be brought into solution by some other agency. The following agencies have been found more or less active in this direction: —

1. Carbon dioxide from the air or from the plant, in solution in dew or rain drops, very gradually brings the copper into solution after the excess lime has been carbonated.
2. Ammonia and nitrous or nitric acids, present in small amounts in rain water, cause some solution of the copper.
3. Organic substances such as sugars, excreted in small quantities from the host cells, bring about very gradual solution.
4. There is some evidence that excretions from the fungus itself bring into solution enough copper to kill it.

Bordeaux Injury. — Bordeaux mixture falls short of the requirements of a good fungicide in that it frequently causes injury to the plant. The copper, brought into a soluble form in one or more of the ways enumerated above, enters the tissues of the plant directly through the epidermal walls by a process of osmosis, or through the stomates, lenticels or wounds. The invaded cells are killed by the toxic copper. On leaves this results in definite dead spots or irregular areas on margins or tips. More or less defoliation may result on fruit trees. On fruits, the death of some of the cells incites the production of protective cork cells, thus causing the rough russet areas which disfigure the surface of fruits such as apples or grapes. The extent of the injury varies with the hosts, being most severe on peaches and plums, and less so on apples, grapes and potatoes, but varying even here with the variety, weather conditions, stage of development and many other factors. No host seems to be immune under all conditions. Apparently, continued rainy weather increases injury. According to Hedrick (33) it is not prevented by the use of excess lime. The apple growers of Nova Scotia, however, use an excess lime Bordeaux, 3–10–50, which is found to be effective against scab, while it greatly reduces the russeting of fruit which results from use of the ordinary Bordeaux formula.

(2) *Commercial Bordeaux Preparations.*

The home preparation of Bordeaux mixture has a number of disadvantages: —

1. It involves a number of distinct operations which require considerable time.
2. The grower must keep in mind the proportions and various directions for preparation, or always have available the printed directions for the same (considered a nuisance by the average grower).
3. A number of suitable containers are required and are frequently not at hand when needed.
4. Few growers keep on hand a supply of quicklime, and even at the store it cannot always be obtained when wanted and of the quality wanted, especially in small quantities. When a barrel of lime is opened, it quickly carbonates, and the merchant in the small place is reluctant to break a barrel for a few pounds; while for the same reason the small grower does not wish to try to keep it at home.
5. The addition of a suitable insecticide in proper proportions increases the above objections.

The grower who uses large quantities of material may not hesitate to go to all this trouble, but the grower who operates on a small scale demands a fungicide which can be purchased ready-mixed, insecticide included, and which needs only to be diluted with water according to the directions on a convenient-sized package to be ready to apply. As early as 1893 — possibly earlier — Leggett & Brother of New York were putting on the market a dry Bordeaux. The Bowker Insecticide Company of Boston sold the concentrated paste "Bodo" at least as early as 1895. Since that time a great number of ready-mixed copper fungicides, usually with the insecticide included, have come into the market: *e.g.*, Pyrox, Caascu, Kiltone, Adheso, Bordo-Lead, Tuber Tonic, etc.

Guaranties. — In compliance with the insecticide act of 1910, and the various rules and regulations which have been promulgated in interpretation of it, every package of commercial copper fungicide (not materials such as copper sulfate (bluestone), etc.) has on the label a statement of (1) the percentage of metallic copper, and (2) the percentage of inert ingredients which it contains. Thus one well-known commercial brand of dry Bordeaux mixture, typical of most of them, is guaranteed as follows: —

Active ingredient, metallic copper, not less than 11 per cent.
Inert ingredients, not more than 89 per cent.

The percentage of copper varies in different brands from 1.5 per cent to as much as 25 per cent, being, of course, higher in the powdered copper fungicides than in those which contain various percentages of water.

In case an insecticide which contains copper, *e.g.*, Paris green, is included, the guaranty states the amount of copper present as copper of Bordeaux, and in addition may also state the total amount of metallic copper in both the fungicide and the insecticide. In this case the copper of Bordeaux should be used as the basis for calculating the value of the substance as a fungicide. To the purchaser who has been accustomed to thinking in terms of 4–4–50 Bordeaux mixture, this statement of ingredients may mean but little. For this reason, Table II on page 33 is presented, interpreting the guaranties in terms of the standard 4–4–50 Bordeaux.

Now, while copper is the only active fungicidal principle in many of these materials, the value of a fungicide does not vary directly as the percentage of metallic copper. The physical character after it is diluted determines its power to cover and adhere to the foliage of the plant to be protected. A fungicide which is washed from the foliage with the first rain is worthless. It is just as important that the commercial substitute shall on dilution produce a voluminous gelatinous precipitate which "stands up" well as it is for the home-made Bordeaux. Commercial fungicides which lack this physical character are deficient in adhesive quality, and are therefore inferior to home-made Bordeaux, although they may contain as much copper.

The final test of the efficiency of a fungicide, however, is its proved ability in the field or experimental plot to check the disease for which it is used. It has been demonstrated in the field that many of these commercial copper preparations have value, but we know of no case in which carefully confirmed and repeated experiments by unbiased experimenters have shown them to be equal in efficiency to freshly prepared Bordeaux mixture. They are being rapidly improved, however, and we do not despair of seeing on the market within a few years an entirely satisfactory commercial Bordeaux preparation.

(3) *Pickering Sprays.*

These fungicides, variously called Woburn Bordeaux, lime-water Bordeaux, or Pickering sprays, were devised and investigated by Bedford and Pickering (34) of the Woburn Experimental Fruit Farm in England. They are made by mixing clear saturated limewater with dilute solutions of copper sulfate. It is claimed that they are more economical than Bordeaux, in that they contain no excess lime, and the copper is more efficient. They are said to deteriorate less rapidly than Bordeaux and are more easily applied. They have been but little investigated or used in America. Cook (35), however, after three years' tests, finds them just as effective as Bordeaux 4–4–50 for control of diseases of potatoes and cranberries in Maine and New Jersey. They did not injure the foliage, possessed good covering and adhesive properties, and apparently possessed the same stimulative properties. These sprays have not been used in Massachusetts.

2. Sulfur Fungicides.

The use of sulfur for disinfection of diseased plants was a common horticultural practice many years before the discovery of Bordeaux mixture. The date of its origin has not been recorded. It was sometimes used alone as a dust, and sometimes mixed with other substances such as lime. Thus in 1833 William Kenrick (36) recommended a mixture of 1½ pints of sulfur, a piece of quicklime as large as the fist, and 2 gallons of boiling water as a remedy for mildew of grapes. "Grison liquid," first prepared by a Frenchman, Grison, in 1851, was considered at that time very effective, and is of historical interest as being a prototype of our modern lime-sulfur solution. A mixture of flowers of sulfur, freshly slaked lime, and water was boiled for ten minutes, and the supernatant liquid diluted and applied with a sponge, especially for control of mildews (37). In these early years, it should be noted, sulfur fungicides were never applied for protection, but as cures. The idea of protective spraying seems never to have been considered previous to the discovery of Bordeaux mixture.

(1) *Lime-sulfur Solutions.*

The introduction of lime-sulfur into California from Australia for the control of San José scale has been described elsewhere in this bulletin (page 13). Shortly after the peach growers of that State began using it for the scale (about 1880), they noted that peach leaf curl, a fungous disease, was also controlled by the dormant spray. It immediately began to come into general use as a fungicide, first in the West, then in the East. Its use as a protective spray for other plant diseases began about 1907, with the observation by Cordley of Oregon (38) that when the dormant spray for scale was applied so late that the apple leaves had already unfolded, the scab disease was also checked. Experiment stations in all parts of the country began to investigate it, and within a few years it had almost supplanted Bordeaux as a spray for the apple orchard and for many other crops.

Formulas for Application. — Most of the commercial brands of lime-sulfur test about 33° by the Baumé hydrometer. As a summer spray for the orchard, this should be diluted at the rate of 1¼ gallons to the barrel. If the home-made solution is used it should be tested with the hydrometer, and the rate of dilution ascertained by consulting the dilution table on page 15 of this bulletin. The dilution for dormant spray (*e.g.*, for peach-leaf curl) is the same as recommended for San José scale under insecticides on page 15.

Effect on the Fungus. — When lime-sulfur is exposed to the air on the foliage, a process of oxidation begins (see page 14 for the equations representing this process), which results in the liberation of sulfur in a very fine state of division. It is the opinion of most investigators that it is this nascent sulfur — not the sulfite, sulfate or thiosulfate of calcium — which is of fungicidal value. The free sulfur is probably gradually oxidized further to sulfur dioxide, which in water forms sulfurous, and on further oxidation, sulfuric acid. Both sulfurous and sulfuric acid are toxic to fungi. There is probably some chemical reaction between the acid and the protoplast of the fungus which results in the death of the latter.

Lime-sulfur Injury. — Lime-sulfur solutions are superior to Bordeaux mixture in that they cause less injury to foliage and rarely any fruit injury. Under certain conditions, however, which have not been very well defined, injury has resulted. Wallace (39) finds that this injury differs from that produced by Bordeaux in that it appears within a very short time after the spray is applied, and infers from this fact that it is due to the burning effect of the soluble polysulfides before the solution has dried on the leaves. It most often appears as irregular dead areas on the margins and tips of leaves where the liquid collects in larger drops and becomes more concentrated as it dries. Hence he warns against drenching the leaves. Addition of lime seems to have no effect on this injury. Injury is worse where the leaves have been previously wounded by insects, scab or other agencies, and the solution has direct access to the interior tissues. Different crops show different degrees of susceptibility to injury. Peach trees are often entirely defoliated by lime-sulfur of a strength that is entirely safe on apples. Pears show varietal differences in this respect, the Duchess being very easily injured. The orchardists of Nova Scotia have within the last few years almost abandoned the use of lime-sulfur spray because it causes a serious dropping of the fruit. Such damage has not been noted in this State.

(2) *Self-boiled Lime-sulfur.*

The use of mechanical mixtures of sulfur and lime dates far back into the history of plant-disease control. Freshly slaked lime provided a cheap base for a paste suitable for applying and distributing the flowers of sulfur. The only sources of heat in these early mixtures were the hot water sometimes recommended for mixing, and the reaction of the lime in slaking. But sulfur fungicides were almost forgotten during the quarter century which followed the introduction of Bordeaux. The use of the self-boiled mixture in its present form was revived by Scott (40) of the United States Department of Agriculture in 1907 for the control of brown rot and scab of peaches. Bordeaux mixture and sulfur fungicides which contain sulfur in solution were found to be highly injurious to peach foliage when applied at a concentration sufficient to control these diseases. Scott found that this mixture, which contains but a very small percentage of soluble sulfur at most, gave good control of the diseases and caused no burning of the foliage. Within a few years it became the most extensively used and successful fungicide for peaches and plums throughout the country. Objections to the use of self-boiled lime-sulfur are: —

1. The poor suspension of ingredients necessitates constant strong agitation and frequent cleaning of nozzles.
2. Especially in dry seasons, it leaves deposits on the fruit if applied within a few weeks of ripening.
3. The labor costs of preparation are exceedingly heavy.

Formula. — The 8-8-50 formula is now used almost exclusively (8 pounds of quicklime, 8 pounds of sulfur, 50 gallons of water).

Physical and Chemical Properties. — This is a mechanical mixture, or, at most, there is only a minimum amount of chemical union between the lime and sulfur. In explanation of the part played by the lime, Scott (41) says: "The intense heat seems to break up the particles of sulphur into about the physical condition of precipitated sulphur, and the violent boiling makes a good mechanical mixture of the lime and sulphur. The finely divided sulphur is depended upon for the fungicidal action rather than the sulphids in solution." The lime also gives adhesive qualities.

The result, then, is the same in the end, whether the commercial lime-sulfur or the self-boiled is used, — sulfur in a finely divided form is deposited on the leaves, and the fungus is killed or checked in its development as described above (page 26).

(3) *Sulfur Dust.*

The use of sulfur dust as a protective application was first begun in New York State and most energetically pushed by Whetzel, Reddick, Blodgett *et al.* of the Cornell Experiment Station. Since its beginning in New York State in 1912, experiment station workers in Michigan, Georgia, Illinois, Virginia, West Virginia, Maryland, Nova Scotia, and Ontario have conducted orchard tests with the dust as a possible substitute for the lime-sulfur and lead arsenate spray. The published results from New York, Michigan, Illinois, Nova Scotia, and Ontario indicate an efficiency equal to that of lime-sulfur and lead arsenate for the control of apple scab and codling moth. Virginia and West Virginia workers report satisfactory control of codling moth, but find it unsatisfactory for black rot, bitter rot, rust and scab of apples, and (in Virginia) for brown rot of peaches. Peach dusting experiments in Georgia and West Virginia indicate an efficiency against scab and curculio equal to that of the sulfur spray, and slightly less control for brown rot. Results in Maryland are less favorable to control of orchard fungi by dusting than by spraying. Whether it is better to dust than to spray and just what diseases can be better controlled by dusting are questions that have by no means been fully answered. Dusting has many opponents as well as advocates among both scientists and practical growers. No great body of experience has yet been developed in Massachusetts, and lacking this, the question cannot be satisfactorily answered.

Formulas. — The sulfur dust is still in the experimental stage, and the proportion of sulfur to lead arsenate or to inert "fillers" has not become standardized. The most used formula calls for 90 parts of very finely ground sulfur to 10 parts of the fluffy type powdered lead arsenate. "Fillers," such as hydrated lime, "terra alba," etc., have been used in some places. The material may be bought ready-mixed or mixed with machine at home. Various types of dusting machines for application are now on the market.

II. DISINFECTANTS.

1. Corrosive Sublimate.

This fungicide (known also as mercuric chloride or mercury bichloride) is used only as a disinfectant. Its toxicity to foliage and its solubility prevent its use as a spray. Its only use in Massachusetts on the farm or in the orchard is for disinfection of seed potatoes and of wounds on trees produced by pruning, canker removal, etc. Corrosive sublimate is a white, dry crystalline salt which may be secured in the market in the powdered form or as tablets. The tablets, which are commonly purchased at drug stores, are of such a size that one tablet produces a 1–1,000 solution when dissolved in a pint of water.

Formula. — Corrosive sublimate for all purposes is used at a dilution of 1–1,000. This dilution may be secured by dissolving 2 ounces of the salt in 15 gallons of water.

2. Formaldehyde.

Formaldehyde is a toxic gas extensively used as a disinfectant since 1888. Its ability to kill fungi and bacteria is dependent on its reducing power, that is, on its power to remove oxygen from matter with which it comes in contact. The formaldehyde (formalin) which is sold on the market is a solution of the gas in water. According to the United States standard of purity for interstate commerce, 37 per cent of the weight must be formaldehyde gas. Although commonly spoken of as a 40 per cent solution, analyses of samples in recent years have shown it to be frequently much lower, even down to 32 per cent. Also, a white sediment (paraformaldehyde) is frequently deposited in the bottom of containers. Since the formation of paraformaldehyde lowers the percentage of formaldehyde, the solution should be warmed until the white sediment has disappeared before it is used. Commercial formaldehyde also contains 5–10 per cent or more of wood alcohol, but this does not impair its fungicidal value. The fumes are very irritating to the nose and eyes, but it is a safer disinfectant than corrosive sublimate.

Uses and Formulas. — The use of formaldehyde (formalin), at a dilution of 1 part in 240 (1 pint to 30 gallons), for disinfection of seed potatoes against scab has now been almost discontinued in favor of corrosive sublimate because the latter is also effective against black scurf.

For disinfection of grain seed against smut, a dilution of 1–240 is recommended except where the spray method is used. In the latter case equal parts of commercial formaldehyde and water are used.

For onion smut the 1–128 formula has been recommended most extensively.

C. COMBINED INSECTICIDES AND FUNGICIDES.

Most farm and orchard crops suffer from both insect pests and fungous diseases. This necessitates the use of both an insecticide and a fungicide on the same plant. Frequently, also, the presence at the same time of more than one species of insect requires the application of both a stomach poison and a contact insecticide. If the crucial time for application of more than one should be approximately the same, it is usually possible and profitable to combine them in a single application. Such a combination results in the saving of one-half to two-thirds of the time required for separate applications, and since labor is usually the big item of expense in spraying, the cost is materially diminished. Unfortunately, however, it is not possible to combine indiscriminately the various substances which are used as fungicides and insecticides. Frequently, in combining two or more of them a reaction takes place which results in —

1. Complete or partial neutralization of the beneficial qualities of one or more.
2. Formation of a new compound which will injure the plant.
3. Liberation of some harmful element.

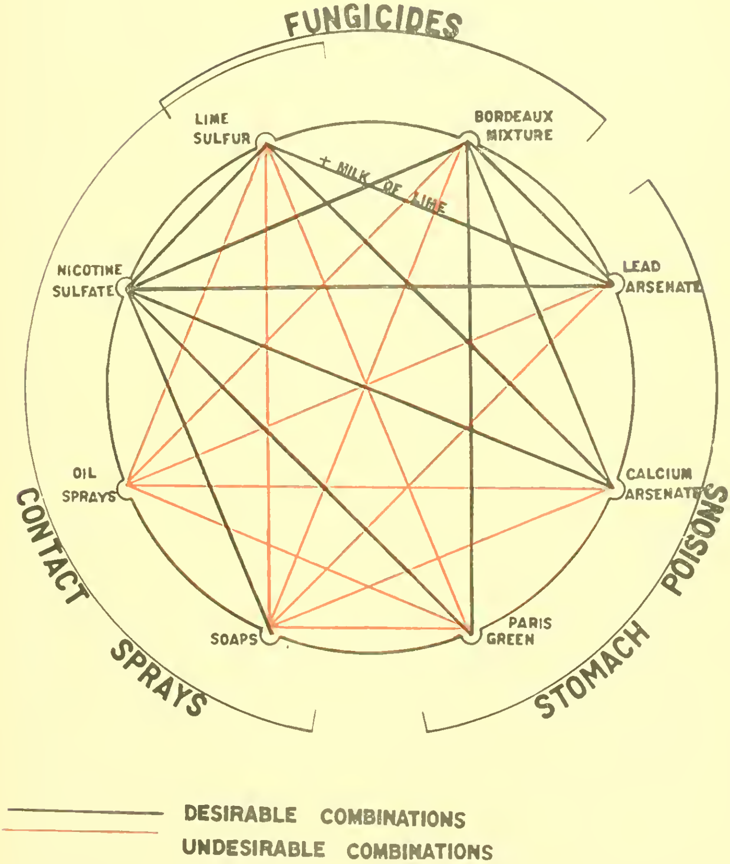
Such substances are said to be incompatible. It should not be understood, however, that chemical combinations between fungicides and insecticides are always harmful or undesirable. Sometimes the reaction is known to increase rather than decrease the fungicidal value; in other combinations the substances have no effect on each other. The possible combinations are discussed below, and the compatibilities graphically represented in the diagram opposite this page.

In making combinations, the formulas and methods of preparation should be the same as have been previously described for each material.

1. Bordeaux Mixture with Lead Arsenate or Calcium Arsenate.

Bordeaux mixture can be combined safely with lead arsenate or calcium arsenate. There is, however, some experimental evidence to show that, in such a combination, the fungicide inhibits the action of the arsenical to a considerable extent (42). On the other hand, the excess lime of the Bordeaux combines with any arsenic rendered soluble by atmospheric conditions, thus diminishing the danger of foliage injury. Owing to its superior adhesive qualities, lead arsenate is better than calcium arsenate for combination with Bordeaux. On the other hand, calcium arsenate is much cheaper. The choice between these, therefore, seems to be a matter of personal preference.

MIXING SPRAY MATERIALS.



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2. Bordeaux Mixture with Paris Green.

These two can be combined safely. The excess lime in the Bordeaux unites with any free arsenic which may be present in the insecticide, and thus protects the leaves from arsenical injury. Paris green also has fungicidal value (43); the combination, therefore, is slightly more beneficial than the fungicide alone. No injurious or neutralizing reaction occurs between the two materials.

3. Proprietary Copper Preparations.

Most of these preparations have the constituents of Bordeaux mixture with the addition of a stomach poison, usually lead arsenate but occasionally Paris green. Both are compatible with the fungicide, and the effect should be the same as previously described for combinations of these arsenicals with Bordeaux.

The tendency of manufacturers of commercial copper mixtures has been to recommend the dilution of their product to a copper content lower than that of 4–4–50 Bordeaux. Within recent years, however, they have been increasing the amount of copper and recommending a more concentrated application. The percentage of arsenic has been more nearly that recommended by entomologists for control of insects. Thus when the purchaser has mixed in his spray tank enough of a low-copper preparation to conform to the standard given in Table II, he will have the arsenical in great excess of the amount needed, and therefore is paying a very high price for his arsenic.

The manufacturer is required to state on the label the amount of arsenic which is present, either as metallic arsenic or as arsenic or arsenous oxide. As an aid to the purchaser in making dilutions and in estimating the value of the preparation, Table II shows the guaranteed arsenic content and the amount of material required to furnish arsenic equivalent to the standard formula (0.293 pound of metallic arsenic to 50 gallons of water).

4. Bordeaux Mixture with Lead Arsenate or Calcium Arsenate and Nicotine Sulfate.

These materials are compatible and make an efficient combination. Some hesitancy was felt at first in regard to the safety of such a combination, owing to the supposed reaction between copper and tobacco compounds, and the possibility of serious burning of foliage by the resulting products (44). It has been demonstrated, however, by chemical analyses and extensive field tests, that there is no objectionable reaction when nicotine in the form of sulfate is combined with Bordeaux mixture; hence this combination may be used (45).

In preparing this spray the nicotine sulfate should be added just before application, and thorough agitation should be given to insure an even distribution of the highly concentrated nicotine product throughout the mixture.

Soap should *never* be added when nicotine sulfate is used in this combination.

5. Lime-sulfur with Lead Arsenate or Calcium Arsenate.

The great extent to which sulfur compounds have supplanted copper sprays as fungicides has made this combination probably the most widely used and most important in practice to-day.

When lead arsenate is added to lime-sulfur, a chemical reaction takes place causing more or less decomposition of both materials. This reaction does not decrease the fungicidal value of the mixture. In fact, Wallace (46), in his investigation of apple scab control, found that the addition of lead arsenate increased the fungicidal action of the lime-sulfur by about 50 per cent. The fact has long been recognized that arsenate of lead alone has some value as a fungicide.

The effect of this reaction upon the value of the combination as an insecticide, however, is unfavorable. In the case of the *acid* lead arsenate (90 per cent of that on the market to-day is of this type), the reaction with lime-sulfur results in the formation of a considerable percentage of soluble arsenic, with the consequent danger of severe foliage injury. The addition of milk of lime, 5 pounds to 50 gallons of the mixture, checks this reaction and so reduces the tendency to burn foliage (47). The arsenate of lead should be added to the milk of lime, and the two thoroughly mixed together and then poured into the lime-sulfur solution so that the protective agent may be present when the two active ingredients are brought together.

When calcium arsenate is used with lime-sulfur, so far as known no chemical change takes place which decreases the value of the combination either as an insecticide or as a fungicide. The addition of milk of lime, however, as a precautionary measure seems advisable.

6. Lime-sulfur with Lead Arsenate or Calcium Arsenate and Nicotine Sulfate.

These materials can be combined successfully and effectively. The presence of nicotine sulfate is not known to modify any of the reactions mentioned under 5, and the recommendations there made apply to this combination also.

The suggestions relative to the addition of nicotine sulfate to the spray, and caution regarding the use of soap, apply here as in 4 above.

TABLE II. — *Combined and Uncombined Insecticides and Fungicides.*

Amounts required to furnish metallic copper and arsenic in quantities equivalent to those in a standard 4-4-50 Bordeaux with arsenical.

Commercial Bordeaux.			Commercial Arsenates.		
Guaranty of Metallic Copper (Per Cent).	For 50 Gallons of Spray (Pounds).	For 1 Gallon of Spray (Ounces).	Guaranty of Metallic Arsenic (Per Cent).	For 50 Gallons of Spray (Pounds).	For 1 Gallon of Spray (Ounces).
25.0	4.00	1.25	30.0	1.00	.25
20.0	5.00	1.50	25.0	1.25	.25
15.0	6.75	2.25	20.0	1.50	.50
12.5	8.25	2.50	17.5	1.75	.50
10.0	10.25	3.25	15.0	2.00	.75
9.0	11.25	3.75	10.0	3.00	1.00
8.0	12.75	4.00	9.0	3.25	1.00
7.5	13.50	4.25	8.0	3.75	1.00
7.0	14.50	5.00	7.0	4.25	1.25
6.5	16.00	5.00	6.0	5.00	1.50
6.0	17.00	5.50	5.0	5.75	2.00
5.5	18.50	6.00	4.5	6.50	2.00
5.0	20.00	6.50	4.0	7.00	2.50
4.5	22.50	7.00	3.5	8.00	2.75
4.0	25.50	8.00	3.0	10.00	3.25
3.5	29.00	9.00	2.5	12.00	3.75
3.0	34.00	12.00	2.0	15.00	4.75
2.5	41.00	13.00	1.5	19.50	6.25
2.0	51.00	16.00	1.0	29.00	9.50
1.5	68.00	22.00	.5	58.00	19.00

APPENDIX.

Commercial Bordeaux Mixtures.

Brands and Guaranteed Composition.

Manufacturer and Brand.	Metallic Copper (Cu) (Per Cent).
J. A. Blanchard Company, New York City: —	
Lion Brand,	4.00
Lion Brand (dry),	11.00
Corona Chemical Company, Milwaukee, Wis.: —	
Corona Dry Bordeaux Mixture,	11.00
Dow Chemical Company, Midland, Mich.: —	
No brand name given,	25.00
Grasseli Chemical Company, Cleveland, Ohio: —	
Bordeaux mixture (dry),	13.00
Sherwin-Williams Company, Cleveland, Ohio: —	
Fungi-Bordo,	11.00
Sterling Chemical Company, Cambridge, Mass.: —	
Sterlingworth (liquid),	3.00
Sterlingworth (dry),	10.00

Commercial Bordeaux with Insecticides.

Brands and Guaranteed Composition.

Manufacturer and Brand.	Metallic Copper (Cu) (Per Cent).	Metallic Arsenic (As) (Per Cent).
Bowker Insecticide Company, Boston, Mass.: —		
Pyrox,	2.30	3.42
Detroit White Lead Works, Detroit, Mich.: —		
Rogers Leaded Bordo,	10.50	2.75
Frost Insecticide Company, Arlington, Mass.: —		
Bordo Lead,	5.00	2.90
Interstate Chemical Company, Jersey City, N. J.: —		
Bordo Lead,	2.00	5.00
Sherwin-Williams Co., Cleveland, Ohio: —		
Pestroy,	10.50	2.75
Tuber Tonic,	6.00	24.00
Sterling Chemical Company, Cambridge, Mass.: —		
Sterlingworth Ar-Bo,	4.00	1.65
Thomsen Chemical Company, Baltimore, Md.: —		
Bordo Lead, Orchard Brand,	5.40	3.90
Toledo Rex Spray Company, Toledo, Ohio: —		
NuRexo,	12.70	3.60
Leggett & Brother, New York City: —		
Dry Bordeaux and Paris Green Compound,	7.00	12.50
Sterling Chemical Company, Cambridge, Mass.: —		
Sterlingworth Dry Bordeaux and Paris Green Compound,	9.00	2.00

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BULLETIN No. 202.

DEPARTMENT OF BOTANY.

RUST OF ANTIRRHINUM.[1]

BY WILLIAM L. DORAN.

Introduction.

The cultivated snapdragon (*Antirrhinum majus* L.) is a biennial or perennial under culture. It is a member of the family Scrophulariaceæ. The plant was introduced here from Europe. As an escape from gardens it is rare in New England. The snapdragon has been a popular garden flower for two hundred years, but only within the last ten years has it been grown to any extent as a greenhouse crop. There has been an increasing demand for it as a cut flower, and consequently an increasing amount of glass has been devoted to its culture. As a florist's crop, the snapdragon may be classed as about equal in importance to mignonette, schizanthus, stocks, pansies and primulas (Nehrling, 1914), varying, of course, in different localities.

Growers have propagated principally for the best colored blossoms and the best formed spikes, and relatively slight attention has been paid to the susceptibility of the plants to disease. Increased and intensive cultivation seem to have weakened this once hardy plant, for it is now affected severely by at least four fungous diseases. The diseases of snapdragon, other than rust, are: anthracnose or leaf-spot, caused by *Colletotrichum Antirrhini*, Stew. (Stewart, 1900), and stem-rot and leaf-spot, caused by *Phyllosticta Antirrhini*, Syd. (Guba and Anderson, 1919).

Rust is the most serious of the diseases of snapdragon under glass; but according to the observation of the writer, anthracnose is in most years a more serious disease than rust on plants grown outdoors. The investigation of snapdragon rust was undertaken by the writer because of the economic importance of the disease, and because so little information

[1] Presented to the faculty of the Graduate School of the Massachusetts Agricultural College (May, 1917) in partial fulfillment of the requirements for the degree of master of science. Literature citations are brought up to the date of presentation for publication (January, 1921). The writer wishes to express his indebtedness to Prof. A. V. Osmun of the Massachusetts Agricultural College and to Dr. O. R. Butler of the New Hampshire Agricultural Experiment Station, under whose direction the work here described was carried on.

concerning the disease was available to the growers. Rust causes loss in at least three ways. A spike of snapdragon blossoms is useful only when it is beautiful, and the rust pustules on leaves and stem considerably mar the appearance and hence lessen the value of otherwise salable spikes. An attack of rust impairs the vitality of the host plant, and results in smaller flowers and shorter spikes than the normal. In severe cases the stems and branches are girdled, causing the death of the plant.

History and Distribution.

Snapdragon rust was found in California in 1895 (Blasdale, 1903). The causal organism was described in 1899 under the name of *Puccinia Antirrhini* Diet. and Holw. (Dietel, 1899). In 1913 the disease was found in Illinois, and in 1914 it was found in Ohio and Indiana (Rees, 1914). By 1915 the rust had appeared in Wisconsin and Iowa (Peltier, 1919). In 1915 the writer observed the disease in Maine, New Hampshire, Massachusetts, Rhode Island and Connecticut, and it was well established in New England, both out of doors and under glass. In this year, also, it was reported from Oregon (Bailey, 1915). In 1916 it was reported from Guelph and Montreal, Can., and also from Alabama (Peltier, 1919). It was found in Nebraska in 1916–17, and is now known to occur in Missouri (Thurston, 1919). Snapdragon rust is evidently generally distributed over the United States, more especially in the northern part.

Symptoms.

Snapdragon rust may occur on plants of all ages from cuttings and seedlings just beginning to show foliage leaves up to mature blossoming plants. A severely attacked snapdragon has a most dejected appearance. The leaves hang limp and wilted as if the plant had been deprived of water, the flowers open small and prematurely, and leaves and stems bear chocolate-brown powdery pustules each edged by a yellowish ring. Leaf blades, petioles, stems and calyces are attacked. Usually the lower leaves of the plant are most affected.

In the early stages there appear on the under side of the leaves swollen yellow patches just inside the epidermis. These yellow patches are 1 to 7 mm. in diameter. At this time the leaf may curl slightly. About forty-eight hours after these yellow patches first appear the epidermis is ruptured, exposing brown powdery masses beneath. These brown spore masses, the uredinia, have been described as being usually circularly grouped (Clinton, 1915), but according to the writer's observation this circular grouping is not an especially dependable characteristic. On the upper surface of the affected leaves are yellow blotches, corresponding in position to the uredinia beneath. The spore powder in the uredinia is in an agglutinate condition at first, but after a few days it becomes dry and dusty and is easily blown about. The uredinia are not sunken. They are confluent with age. The ring of ruptured epidermis surrounding a uredinium is soon concealed by this brown spore powder.

PLATE I.

Snapdragon plant attacked by *Puccinia Antirrhini.*

The uredinia on the stem are much elongated. Here the ruptured epidermis is more noticeable than on the leaves. Uredinia on the stem usually occur at the base of a petiole, or at the crotch of two branches, or any place where water may stand. It is the girdling of the stem by uredinia which causes the branch or plant to wilt and die. It is not especially common, however, for snapdragon rust to cause the death of the host plant.

The telia are black, not brown. They are leathery, not powdery, and must be scraped off if they are to be removed. Telia are more common on stems than on leaves, but are not numerous anywhere. They are slightly smaller than the uredinia and are usually somewhat sunken, with the ruptured cuticle projecting above them. Teliospores are sometimes borne in the same sorus with the urediniospores, but the telia may be distinguished macroscopically by their blacker color and harder consistency.

In the greenhouse the disease occurs at all seasons of the year, but is more serious and conspicuous during April and May.

Causal Organism.

Morphology.

Snapdragon rust is caused by the fungus *Puccinia Antirrhini* Diet. and Holw. The mycelium of the fungus occurs chiefly between the spongy parenchyma cells of the leaf and between the cortex cells of the stem. It is more abundant in the leaf than in the stem. It is colorless, septate frequently, and branches profusely. It is intercellular and provided with haustoria (Fig. 4, Plate 2). The haustoria are constricted at the point of entrance to the cell. Within they become broader and vase-shaped, or bear short knoblike branches. A dilute solution of eosin makes the haustoria easily visible. A cross section through an infected leaf reveals beneath each uredinium a stroma of interwoven mycelium (Figs. 1 and 5, Plate 2). This stroma underlies the whole sorus, and extends in a ring around its edge. From this stroma the spore-bearing hyphæ arise.

Two types of spores are known in the life cycle of the fungus, viz., urediniospores and teliospores. The urediniospores are spherical to elliptical. They are 22 to 30 microns in length and 21 to 25 microns in diameter. They are borne on pedicels of varying length from which they become detached at maturity. The urediniospores are yellowish brown in color. Their walls are provided with short spines and have two or three germ pores. The teliospores are 36 to 50 microns in length and 17 to 26 microns in diameter. These spores vary greatly in shape (Fig. 2, Plate 2). The apex may be sharply pointed, rounded or truncate; the base is usually attenuated, but may be rounded off bluntly. There is a slight constriction at the septum. The epispores are dark brown to black, and the wall is smooth, possessing no such spines as occur on the urediniospores. Each of the two cells of the teliospore is provided with a germ tube which is apical in the terminal cell and occurs just below the septum of the basal cell.

PLATE II.

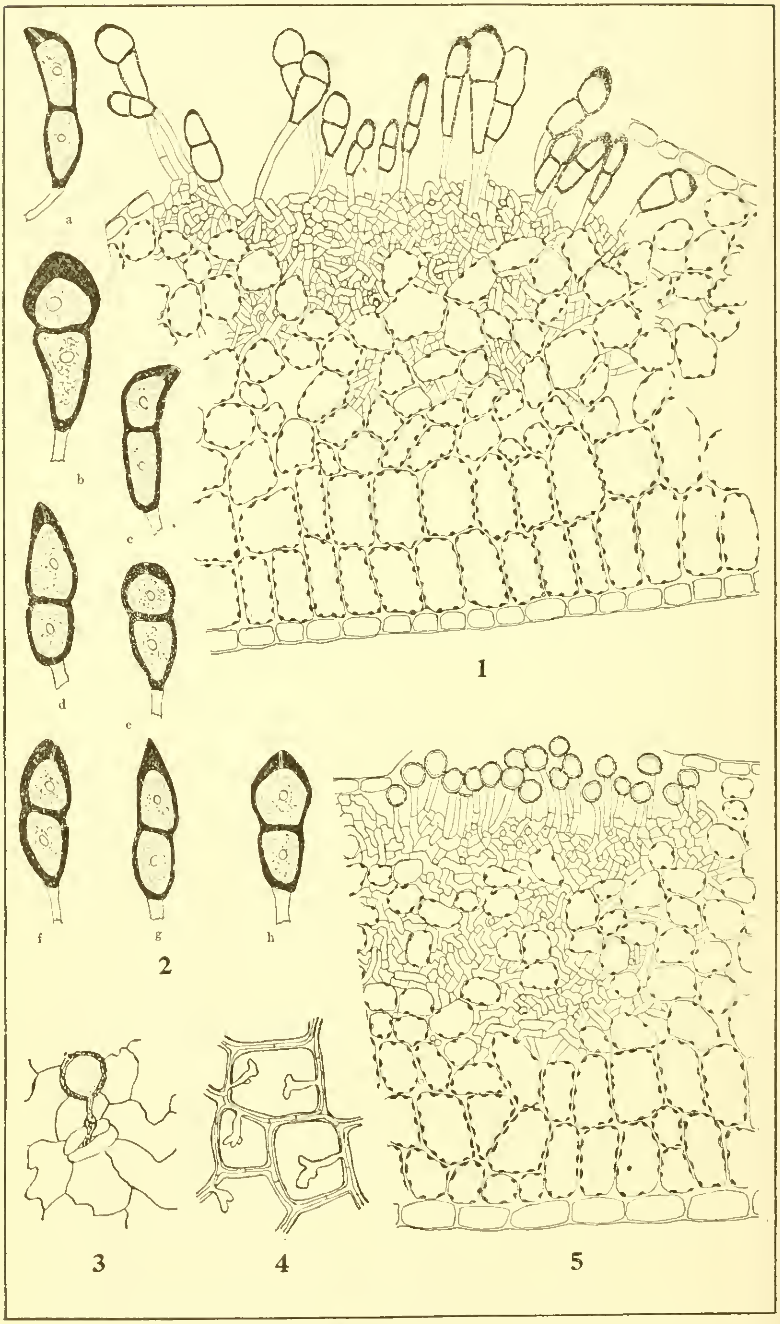


Fig. 1. — Cross section of telium and leaf.
Fig. 2. — Teliospores.
Fig. 3. — Germinating urediniospore on leaf.
Fig. 4. — Haustoria and intercellular mycelium.
Fig. 5. — Cross section of uredinium and leaf.

Occurrence of Spore Stages.

Urediniospores occur at all times on the diseased snapdragons. In the greenhouse these are normally the only type of spores produced.[1] Teliospores occur only rarely in New England. Many infected plants bear only urediniospores, even on the advent of killing frosts. Occasionally teliospores may be found outdoors in November, occurring more often on the stems than on the leaves. In November the writer placed several snapdragons bearing uredinia in wire baskets and allowed them to winter over out of doors in this way. Examination the following March showed only one telium on all the material.

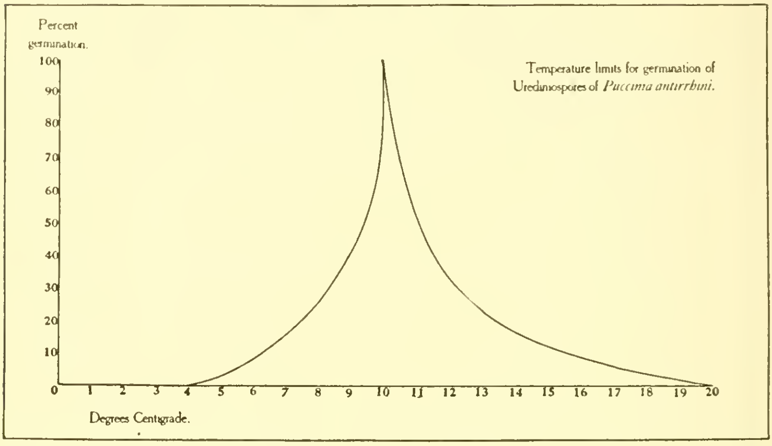
In the greenhouse there is no lowering of temperature to stimulate the formation of teliospores, but their formation is stimulated if the host plant dries out very slowly. When plants were suddenly dried out, no teliospores were formed; but when plants were gradually deprived of water, teliospores were formed in five weeks. Under normal conditions of culture the teliospore may be eliminated as a factor in the greenhouse. No greenhouse snapdragons seen by the writer showed teliospores except those plants gradually deprived of water, as above mentioned.

Spore Germination and Infection Experiments.

The first attempts made to germinate urediniospores were not uniformly successful. As it proved later, this was because the room temperature at which the tests were made was above the maximum temperature for spore germination. The method by which the minimum, optimum and maximum temperatures for the germination of these spores were determined is here described. This method has been previously described by the writer (Doran, 1919).

The spores to be used were removed from infected leaves by a stream of water from a pipette. In this way only mature spores were obtained, while scraping with a brush or wooden instrument would also detach young and immature spores. The spores were shaken in distilled water until they were uniformly distributed through it. Drops of this water containing the spores were then placed on clean slides, and the latter were placed on culture plate benches in moist chambers. These were placed in biological incubators at constant temperatures. About twelve hours later the germinated and ungerminated spores were counted. Most of the spores which germinated did so, however, in five to eight hours. Throughout these tests it was noticeable that no spores in the interior of the drop ever germinated. Only those spores in contact with the air as well as the water germinated, so spores in the interior of the drop were not counted as being present. The distilled water used was not aërated. This aërotropism was not further investigated. Throughout the tests one lot of spores was always run at 10° C. The percentage of germination at 10° C. was taken as a standard, raised to 100, and the other percentages at the different temperatures raised proportionately. This was done in order to bring the data into shape for plotting a constant curve of temperature and germination.

PLATE III.



Curve showing temperature limits for germination of urediniospores of *Puccinia Antirrhini.*

The optimum temperature for the germination of the urediniospores of *P. Antirrhini* was found to be 10° C., the minimum, 5° C., and the maximum, 20° C. When the data are plotted, a curve is obtained that is nearly symmetrical. A most striking fact is that if the temperature is varied 2° C. above or below the optimum, the germination falls off 50 per cent. In the following table each relative germination is the mean of five experiments: —

TABLE 1. — *Relative Germination of Urediniospores of P. Antirrhini Diet. and Holw., compared to the Germination at 10° C. taken as 100.*

5° C.	6° C.	7° C.	8° C.	9° C.	10° C.	11° C.	12° C.	14° C.	15° C.	18° C.	20° C.	30° C.
0	0	27	13	50	100	–	21	0	17.5	2.5	0	0
0	0	0	35	30	100	42	15	12	13	0	1	0
1	4	7	37	50	100	9	32	0	0	0	1	0
0	0	–	4	12	100	14	16	42	6	1.5	0	0
1	4	–	21	30	100	72	–	2	1	1	0	0
0	3	–	–	–	100	–	–	22	–	0.5	0	0
0.3	1.8	11.3	22	34.4	100	34.2	21	13	7.5	.75	0.2	0

Conditions affecting Longevity of Urediniospores.

The spores used in the previously described germination tests were taken fresh from growing plants. It was noticeable that their viability gradually diminished if the leaves dried out long in the room. To determine the longevity of urediniospores, rusted shoots were removed from the plants and placed at temperatures of 0° C., 10° C. and 22° C. Half of this material at each temperature was allowed to dry in open containers, and half of it was kept in closed chambers to prevent its drying out. Spores were removed every seven days and placed at their optimum temperature for germination, with the results shown in Table 2.

TABLE 2. — *Effect of Temperature and Drying on the Longevity of the Urediniospores of P. Antirrhini.*

Percentage of germination of urediniospores.

Storage Period (Days).	Storage Temperature.					
	Dry.			Moist.		
	0° C.	10° C.	22° C.	0° C.	10° C.	22° C.
7,	55	50	40	52	52	50
14,	35	25	28	35	20	25
21,	20	20	15	18	12	20
28,	12	15	12	18	15	15
35,	1	2	3	10	6	5
42,	0	0	0.5	3	2	2
49,	0	0	0	1	1	0
56,	0	0	0	0	0	0

When this experiment was begun, 60 per cent of the spores germinated. Some of the spores in moist air retained the power of germination forty-nine days, and in dry air, forty-two days. Some of the spores at 0° C. and at 10° C. retained the power of germination forty-nine days. It is evident that exposure to freezing temperature does not shorten the life of urediniospores. In Massachusetts the snapdragon remains green and lives through mild winters with no protection, and lives through harder winters if protected by a mulch. In January the writer obtained urediniospores from green plants growing outdoors in Massachusetts. These urediniospores germinated readily when placed at the optimum temperature for germination, but after these plants had been dried three weeks at room temperature the spores no longer germinated. Temperature is of less importance than drying in shortening the life of urediniospores.

To determine the effect of temperature on infection, twelve plants were sprayed with fresh spores distributed in distilled water. Four of these plants were placed at a temperature of 10° C., four at 15° C. and four at 18° C. The plants used were of a susceptible variety, Carter's Pink, but they were free from disease when selected, and from a disease-free bench. The plants remained in the above-mentioned temperatures twelve hours, after which they were all placed in the greenhouse at the same temperature.

Seven days later the stromata were visible. Ten days after inoculation the uredinia began to appear. One week later the number of sori on the plants was counted, with the results shown in Table 3.

Table 3. — *Effect of Temperature on the Infective Power of the Urediniospores of P. Antirrhini.*

Temperature at which Plants were inoculated.	Number of Sori per Plant.				Mean Infection in Relative Numbers.
	Plant A.	Plant B.	Plant C.	Plant D.	
10° C.,	240	265	210	180	100.0
15° C.,	9	6	15	20	7.6
18° C.,	5	3	7	9	3.5

It is thus seen that raising the temperature 5° to 8° C. above the optimum for germination of the urediniospores causes the amount of infection to fall off more than 90 per cent.

As a further test of the effect of temperature on infection of snapdragon by *P. Antirrhini*, plants of a susceptible variety were inoculated in two different greenhouses, having a night temperature of 10° C. in one case, and 15° C. in the other. Fifteen days after inoculation the plants in the greenhouse at 15° C. bore an average number of twelve uredinia, and the plants in the greenhouse at 10° C. bore an average number of one hundred and twenty uredinia.

As indicated by the results with *P. Antirrhini*, the rusts are able to germinate best at rather low temperatures. A consideration of the literature also supports this view. Erikson (1895) discovered that low temperatures are suitable to the germination of rust spores. He found that the spores of *Æcidium Berberidis* germinate best when cooled for seven hours to 3° C., and that the spores of *Peridermium strobi* germinate best when cooled for twenty-four hours to 6.5° C. He found the optimum temperature for the germination of the spores of *Uredo glumarum* to be 4.5° C., and that the spores of *Uredo coronata* germinate best after being cooled for sixteen hours to a temperature of —10° C. In the last case it seems probable that he went below the optimum temperature, and that the spores germinated when the temperature again rose to the optimum.

Howell (1890) found that the urediniospores of *Uromyces Trifolii* (Alb. and Schw.) Wint. germinate best between 11° and 16° C. They do not germinate below 7° C. nor above 21° to 25° C. If the minimum, optimum and maximum temperatures for germination of *U. Trifolii* are taken as 7° C., 11° C. and 21° C., respectively, this fungus has about the same temperature-germination relation as has *P. Antirrhini*, the minimum, optimum and maximum temperatures for germination of urediniospores of *P. Antirrhini* having been found by the writer to be 5° C., 10° C. and 20° C., respectively.

Experiments on Germination of Teliospores.

Numerous attempts to germinate teliospores were made with fresh material, dried material, teliospores produced under glass, teliospores produced outside, and teliospores wintered over outside. These germination tests were made at 7° C., 10° C., 12° C. and 20° C., but in no case did the teliospores germinate. These spores had formed in response to the definite stimulus of cold or drying. They do not germinate when first formed; they are spores of regeneration, and they may be considered as requiring a rest period, like other spores which function to carry fungi through adverse conditions. But these teliospores do not germinate after the rest period, that is, after passing the winter out of doors, when subjected to the range of temperature in which their host normally grows. It is not unlikely that they are killed by the cold, not being able to withstand the rigors of the winters to which their host has been carried.

Peltier (*loc. cit.*) reports that all efforts to germinate the teliospores failed.

The fact that teliospores do not germinate may be explained in another way. The temperature-germination curve for urediniospores is very sharp; and if teliospores have an even narrower range of temperature through which they can germinate, it is possible that the right temperature for germination has not yet been hit upon, since a variation a few degrees above or below the optimum temperature would result in no germination.

According to our present knowledge the teliospores are not only rare, but they do not germinate. This being the case, the possibility of an alternate host is eliminated. But no alternate host is necessary for a rust fungus which passes the winter under glass. The chrysanthemum rust fungus (*P. Chrysanthemi* Roze.) in America dispenses with both an alternate host and teliospores (Atkinson, 1890). Yet this rust occurs both in the greenhouse and out of doors, and persists from year to year. *P. Chrysanthemi* also is independent of the other rusts found on nearly related Compositæ, just as *P. Antirrhini* is not a parasite on other Scrophulariaceous plants, such as Linaria (see below, experiments with Linaria). Carnation rust, *Uromyces Caryophyllinus* (Schrank) Wint. has an alternate host, *Euphorbia gerardiana*, in Europe (Fischer, 1910), but it has not been found on an alternate host in this country. If the teliospores of *P. Antirrhini* ever were functional they seem now to be useless. The urediniospores of this fungus are sufficient to propagate it through the year, as long as greenhouses in the vicinity shelter the host plant during the winter. The urediniospore is a spore of dissemination. Spores of regeneration, such as teliospores, are not a necessity for a fungus the host of which occurs both under glass and out of doors.

The original host of *P. Antirrhini* is not known. Blasdale (*loc. cit.*) concluded that either snapdragon rust originated on the wild form of Antirrhinum (*A. vagans*), or its original host plant was not a member of the Scrophulariaceæ. Peltier (*loc. cit.*) made cross inoculations with several species of Antirrhinum and with several species of Linaria, including *Linaria vulgaris* Mill. He obtained no infection on any species of Linaria. The only species of Antirrhinum except the cultivated snapdragon (*A. majus*) upon which he obtained infection was *A. maurandioides* Gray, in which case a few urediniospores were produced.

The writer made several attempts to infect *Linaria vulgaris* Mill. and *L. Cymbalaria* (L) Mill. by spraying the plants with water containing the urediniospores and placing them at the optimum temperature for their germination (10° C.). There was no infection whatever, although check plants of snapdragon similarly treated became badly rusted. It is unlikely that the rust occurs, at least in New England, on any other host plant than the cultivated snapdragon.

Dissemination.

Many growers take their cuttings at a time when snapdragon rust is at its height in the greenhouse, which is in March, April and May. There are various opinions as to the relative merits of raising plants from seeds and from cuttings, but plants raised from cuttings come true to color, and in the effort to preserve a good variety some growers take rust-free cuttings from a bench showing rust, or they take cuttings bearing spore pustules. Some growers have thought that if the cuttings show no spore pustules they are safe to use, even though they come from a bench of infected plants. The writer propagated plants by cuttings which bore uredinia and by cuttings which bore no uredinia, although taken from an infected bench. After three weeks all of the cuttings which bore uredinia were badly rusted, and 35 per cent of the cuttings which when made were apparently free from disease, although taken from an infected bench, showed the disease. It is evident, then, that cuttings bearing spore pustules may be expected to develop into rusted plants, and that cuttings free from spore pustules, if taken from a bench of infected plants, serve to aid very materially in the dissemination of the fungus. Microscopic examination of the leaf surfaces of these apparently healthy cuttings revealed numerous urediniospores which had fallen there or had been carried there from diseased plants. These spores need only the favorable environment of the cutting bench to cause them to germinate and infect the young plants, and it is therefore usually inadvisable to take cuttings from a house showing rust. Both Peltier (*loc. cit.*) and Stone (1917) consider cuttings as being among the principal means of dissemination.

Proof of the importance of greenhouse insects in the spread of snapdragon rust is not lacking. Three insects often found on snapdragon are the white fly (*Aleyrodes vaporariorum* West), the red spider (*Tetranychus bimaculatus* Harvey) and the common aphid (*Aphis gossypii*). With a binocular microscope the writer examined these insects on snapdragon foliage. They were on healthy plants, but there were rusted plants in the same bench. On the bodies of most of the insects examined were the urediniospores of *P. Antirrhini*.

The third agency by which the fungus is disseminated is watering. Carnation growers in watering make an effort not to wet the foliage any more than is necessary, usually employing a stiff piece of hose or pipe which enables them to get water into the middle of the bench without wetting the plants above. To this simple practice is due in part the decline in importance of carnation rust. The writer selected twenty snapdragon plants of the same variety, all showing uredinia in approximately equal numbers. Ten of these plants were watered only on the soil, no water touching the foliage. The other ten were treated the same, except that their foliage was kept wet. After three weeks the plants with wetted foliage showed 200 per cent more uredinia than they had at the beginning, while the plants whose foliage had been kept dry showed no increase in the number of uredinia. Water is necessary for the germination of the spores and for infection. A carelessly directed stream from a hose loosens spores from pustules, carries them to other plants, and provides them with the necessary moisture for their germination.

Pathological Anatomy.

The upper epidermis of the leaf and the palisade cells are only rarely affected by this disease. Occasionally a few palisade cells are forced apart by hyphæ. The spongy parenchyma cells are principally affected. The parenchyma cells in the immediate vicinity of a sorus do not attain their normal size. Strands of hyphæ force them apart and sometimes cause them to grow into abnormal forms. The chloroplasts fade slightly, but the yellow appearance of the area surrounding a sorus is due mostly to the presence of a stroma of mycelium. After the intercellular mycelium has become well established it develops this firm stroma in contact with the lower epidermis, and often includes scattered spongy parenchyma cells (see Fig. 5, Plate 2). This growing stroma and the rising pedicels of the urediniospores finally rupture the epidermis. The contents of cells containing haustoria do not degenerate unless the whole leaf becomes involved. Attacked cells do not swell, and any hypertrophy on the leaf is due to the development of stromata. Leaf cells of snapdragon which are normally pink lose this pigment when attacked by the fungus. When the sori occur on the stem the epidermis is ruptured, the cortical cells are forced apart, and in some cases the mycelium may be found between the cells of the fibro-vascular bundles. Ordinarily, however, cells as far in as the phloëm are not attacked. The chloroplasts fade even less in the stem than in the leaves. The cells of the cortex do not attain their normal size. Epidermal cells appear unchanged, though raised as a membrane above a sorus. Mycelium in both leaf and stem is local.

Varietal Susceptibility.

The list of commercially grown varieties of snapdragon, such as, for example, Nelrose, Silver Pink, Phelp's White and Keystone, is not large. But there is a large number of varieties listed and grown outdoors. Since there seemed to be but little information available as to which varieties are resistant and which susceptible, the writer tested forty-six varieties. The plants were grown from seed, and when the potted plants had reached a height of 6 inches they were inoculated by being sprayed with water in which urediniospores had been distributed, and placed under bell jars at 10° C. Each variety tested was represented by twelve to twenty individuals.

Two weeks after the date of inoculation the plants were examined and the number of rust pustules and infected leaves were counted. The plants were examined at weekly intervals for the next five weeks, and observations recorded as to the number of rust pustules and infected leaves. In the following table the varieties are grouped according to color, and under each color the most resistant varieties are named first, and the most susceptible varieties are named last, the intermediate varieties being so arranged that any variety is more resistant than those which follow it. Varieties equally resistant or susceptible are connected with brackets. By means of the relative numbers in the table it is possible to compare varieties of different colors as regards resistance.

Unfortunately, the most valuable commercial varieties, such as Nelrose and Silver Pink, are very susceptible to the rust.

The following table is perhaps not of great value to florists, since they must grow the varieties most in demand. But this table of relative susceptibility could be used as a basis in breeding resistant varieties, and by its use the amateur grower of snapdragons can avoid the more susceptible varieties, and still have a satisfactory garden of snapdragons.

TABLE 4.—*Relative Susceptibility of Antirrhinum Varieties to P. Antirrhini.*

Varieties.	Scale, Relative Numbers.	Varieties.	Scale, Relative Numbers.
White.		*Variegated or Mixed Colors.*	
Queen of the North,	0	Striped Variety,	0
Pure White,	0	Bronze Queen,	72
Giant White,	0	Niabe,	93
Phelp's White,	0	Fairy Queen,	93
Queen Victoria,	0	Carter's Gold Crest,	100
Mont Blanc,	0	*Red.*	
Yellow.		Crimson,	0
Giant Yellow,	0	Giant Blood Red,	0
Hephætos,	9	Fire Brand,	0
Dwarf Golden Queen,	100	Scarlet,	9
Sulphur Yellow,	100	Giant Scarlet,	16
Pink.		Dwarf Defiance,	23
Rose Dore,	0	Giant Garnet,	23
Bridesmaid,	0	Dark Scarlet,	37
Giant Rose Pink,	23	Half Dwarf Firebrand,	44
Rosy Morn,	30	Carter's Butterfly,	51
Nelrose,	51	Orange King,	58
Silver Pink,	51	Black Prince,	58
Dwarf Daphne,	65	Deep Crimson,	79
Rose,	86	Coral Red,	86
Giant Pink,	86	Ruby,	100
Dwarf Rose Queen,	93	Fiery Belt,	100
Carter's Pink,	100	Crimson Queen Victoria,	100
Delicate Rose,	100		
Venus,	100		
Chamois,	100		

Cause of Resistance.

Resistance of plants to disease has been explained in two general ways: (1) Resistance may be regarded as being related to certain morphological characteristics. Cobb (1892) considered resistance to fungous disease as being due to small stomata, waxy coating, and thick cuticle on the host. Freeman (1911) found that increase in bloom on barley leaves made the plants more resistant to rust. Valleau (1915) studied resistance of plums to brown rot, and considered resistance to be due to the production of parenchymatous plugs which fill the stomatal cavity, and to lenticels composed of cork cells through which the hyphæ cannot penetrate. (2) On the other hand, the resistance of plants to disease has often been regarded as due not to morphological characteristics, but rather to physiological or chemical factors. Myoshi (1895) concluded that many fungi respond to chemical attraction. According to Massee (1904) infection depends on the presence of positive chemotactic substances in the plant cell. Klebahn (1896) concludes that infection is a kind of conflict between host and parasite. Bolley (1908) attributed resistance to chemical agents, such as toxins, which arise as a result of the fungous attack upon the host. These few citations from the extensive literature on this subject illustrate two views as to the resistance of plants to disease.

The work done by the writer indicates that the resistance of some varieties of snapdragons to rust is due to morphological characteristics rather than to physiological differences. The relative susceptibility of forty-six varieties of snapdragon to rust has already been given. The inoculated plants developed uredinia, some in large numbers and some in small numbers. But on both resistant and susceptible plants the sori were developed in the same length of time, and there was no apparent difference in the vigor of the sori after they had once broken through the epidermis. This seems to the writer to indicate that the difference in susceptibility is not due to chemical factors within the host cells, but rather to mechanical factors preventing infection. The most susceptible plant is the one infected in the most places, that is, the one into which the most germ tubes enter.

Infection of snapdragons by *P. Antirrhini* is always through the stomata. The writer sprayed urediniospores on the living leaves, and eight hours later examined the leaf surfaces microscopically. This was done repeatedly, but at no time was infection seen to occur anywhere except through the stomata. The plants used were kept in both light and darkness, with stomata both open and closed. The germ tubes were protruded, wandered about slightly, and then bent into the nearest stoma, or, if the water on the leaf dried too soon, they shriveled up and never reached a stoma. But no germ tubes were found which had penetrated or were penetrating the walls of the epidermal cells.

The mycelium within the leaf and stem is local; therefore the number of sori on a leaf or stem depends on the number of infections, and, since infection is only through the stomata, it was interesting to determine the connection between the number of uredinia (the index of relative susceptibility) and the number of stomata.

Leaves were taken from three-months-old snapdragons of susceptible and resistant varieties. The number of stomata on the upper epidermis per unit area of leaf was determined. In each case ten countings go to make up the average given for each variety. Ten susceptible and ten resistant varieties were used. The result of these counts is given in the following table: —

Table 5. — *Average Number of Stomata per Unit Area of Leaf.*

Susceptible Varieties.	Resistant Varieties.
3.1	1.5
4.1	1.5
3.0	2.0
2.0	1.0
3.0	1.3
3.3	1.6
3.0	1.1
2.8	1.7
5.0	1.1
3.2	1.8

The averages of these figures show that there are 3.25 stomata on the susceptible varieties to 1.46 stomata on the resistant varieties. Or, stated differently, the resistant varieties have only 45 per cent as many stomata as the susceptible varieties. The susceptible varieties showed approximately 200 per cent as many uredinia as the resistant varieties. This would indicate that in the snapdragon susceptibility is directly proportional to the number of stomata; that is, doubling the number of stomata doubles the number of uredinia or the amount of infection. Such a relation is, of course, relative rather than absolute.

It may be added that the stomata on resistant and susceptible varieties are present in the same numerical relation if both upper and lower epidermis are considered. The figures in Table 5 are for the upper epidermis only, because, owing to the fact that but little water clings to the lower epidermis, infection is mostly through the upper epidermis.

The stoma is the gateway through which the fungus enters. The fewer stomata there are, the fewer infections there will be, and the plant will appear correspondingly resistant.

Control.

Laboratory Toxicity Tests with Copper Fungicides.

In all the toxicological experiments here described the general method used was that of Reddick and Wallace (1910). The fungicides used in these toxicity tests were prepared by Dr. O. R. Butler of the New Hampshire Agricultural Experiment Station. Glass slides were cleaned in potassium bichromate cleaning solution, rinsed in distilled water and dried between filter papers. The solution, the toxicity of which was to be tested, was sprayed on the slide by means of an atomizer, and the slides were then dried for twenty-four hours. Fresh urediniospores were removed from living leaves by means of a stream of water from a pipette. These spores were shaken up in distilled water, drops of which were then placed on the sprayed and dried slides, and also on other unsprayed slides used as checks. This gives conditions similar to those the spores meet on sprayed and unsprayed leaves. The slides bearing the spores were then placed on culture plate benches in moist chambers, and these were placed at 10° C., the optimum temperature for the germination of urediniospores of *P. Antirrhini*. Here they remained for at least twelve hours, when the drops were examined microscopically, the spores counted, and the percentages of spores germinating determined. If there was no germination on the check (unsprayed) slides the results on the sprayed slides were of course discarded. At least three tests were made with each strength of solution. Only dilutions near the limit of toxicity are given in the tables, although stronger and weaker solutions were also used.

Copper sulfate was tested in dilutions ranging from .0039 to .25 per cent copper. The toxicity of copper sulfate is shown in the following table: —

TABLE 6. — *Effect of Various Strengths of Copper Sulfate on the Germination of Urediniospores of P. Antirrhini.*

PER CENT COPPER.	Germination relative to Check, 100.	Remarks.
0.25,	0	Mean of three experiments.
0.125,	5	Mean of three experiments.
0.0625,	5	Mean of three experiments.
0.0312,	12	Mean of three experiments.
0.0159,	18	Mean of three experiments.
0.0079,	14	Mean of three experiments.
0.0039,	24	Mean of three experiments.

It is thus seen that copper sulfate prevents germination of the urediniospores of *P. Antirrhini* at a strength of solution of 0.25 per cent copper. Melhus (1915) found copper sulfate toxic to the spores of *Phytophthora infestans* (Mont.) DeBary when the solution contained .0157 per cent copper. The indications are that the Uredinales are much more resistant to copper than are the Phycomycetes.

To determine the toxicity of copper sulfate to foliage of snapdragon, plants were sprayed with copper sulfate solutions containing from 0.25 to .0312 per cent copper. The sprayed plants were then dried slowly; that is, they were allowed to remain six hours in a moist chamber after spraying. The results are given in the following table: —

Table 7. — *Toxicity of Copper Sulfate Spray to the Foliage of Snapdragon.*

Per Cent Copper.	Injury to Foliage.
0.25,	Markedly injured.
0.125,	Markedly injured.
0.0625,	Slightly injured.
0.0312,	No injury.

It is evident from this that a copper sulfate solution which will prevent germination of urediniospores, a solution which must contain at least 0.25 per cent copper, is toxic to the foliage of the host. Copper sulfate therefore cannot be used as a control for snapdragon rust.

Cuprammonium sulfate (Eau celeste), $CuSO_4.4NH_3.H_2O$, was the next fungicide tested. On drying, this gives rise to basic copper sulfate which on further weathering passes to copper sulfate. In these toxicity tests it was used in strengths of solution containing from 0.008 per cent to 0.5 per cent copper sulfate, with results shown in Table 8.

Table 8. — *Effect of Various Strengths of Cuprammonium Sulfate on the Germination of Urediniospores of P. Antirrhini.*

Per Cent Copper.	Germination relative to Check, 100.	Remarks.
0.1300,	0	Mean of three experiments.
0.0650,	0	Mean of three experiments.
0.0325,	4	Mean of three experiments.
0.0162,	22	Mean of three experiments.
0.008,	45	Mean of three experiments.

As here shown, a solution of cuprammonium sulfate containing 0.065 per cent copper prevents germination of urediniospores of *P. Antirrhini.*

The toxicity of this solution to the foliage of snapdragon was tested as in the case of copper sulfate. Solutions containing 0.25 or 0.125 per cent copper injured the foliage markedly, and a solution containing 0.065 per cent copper produced some injury. Cuprammonium sulfate at the strength toxic to the fungus is injurious to the host plant, and cannot therefore be used.

Other copper salts were not tested, for Melhus (*loc. cit.*) has found cupric sulfate ($CuSO_4.5H_2O$), cupric nitrate ($Cu(NO_3)_2.3H_2O$), cupric acetate ($Cu(C_2H_3O_2)_2.H_2O$) and cupric chloride ($CuCl_2.2H_2O$) to be about equally toxic if they contain the same amounts of the toxic principle, — copper.

Hammond's Copper Solution, a commercial preparation which has been used by florists in attempts to control greenhouse rusts, was next tested. The stock solution as purchased was analyzed by Mr. T. O. Smith, assistant chemist at the New Hampshire Agricultural Experiment Station, and found to contain 0.018 gms. copper in 1 c.c. of solution. The manufacturers recommended that it be applied at the rate of 1 quart of the stock solution to 25 gallons of water, that is, a solution containing 0.018 per cent copper. The results of the tests are given in Table 9.

TABLE 9. — *Effect of Various Strengths of Hammond's Copper Solution on the Germination of the Urediniospores of P. Antirrhini.*

PER CENT COPPER.	Germination relative to Check, 100.	Remarks.
0.18,	5	Mean of three experiments.
0.144,	8	Mean of three experiments.
0.12,	19	Mean of three experiments.
0.072,	18	Mean of three experiments.
0.036,	17	Mean of three experiments.
0.014,	40	Mean of three experiments.
0.018,	72	Mean of three experiments.

It is evident that Hammond's Copper Solution, even when used at ten times the recommended strength, does not prevent germination of urediniospores of *P. Antirrhini*. In connection with this work the action of Hammond's Copper Solution on carnation rust was also tested, and at the recommended strength it was not toxic, the germination of the urediniospores of *U. Caryophyllinus* (Schrank) Wint. relative to check, 100, being 56.

Bordeaux mixture was next tested. The Bordeaux mixture used contained copper sulfate and calcium oxide in the approximate ratio of 1 : 0.3; that is, calcium oxide was added to slight alkalinity. This formula was used for the sake of convenience, but the same results would be obtained with any current formula, for the unit copper is equally toxic in acid, neutral and alkaline Bordeaux mixtures (Butler, 1915). The Bordeaux mixture used in the tests was diluted to various strengths, so as to contain the following percentages of copper sulfate: 0.0156, 0.0312, 0.0625, 0.125, 0.25, 0.5, 1, 2 and 4. The results are shown in Table 10.

Table 10. — *Effect of Various Strengths of Bordeaux Mixture 1 : 0.3 on the Germination of the Urediniospores of P. Antirrhini.*

Per Cent Copper Sulfate.	Per Cent Copper.	Germination relative to Check, 100.	Remarks.
4.0,	1.0	24	Mean of three experiments.
2.0,	0.5	25	Mean of three experiments.
1.0,	0.25	15	Mean of three experiments.
0.5,	0.125	32	Mean of three experiments.
0.25,	0.0625	33	Mean of three experiments.
0.125,	0.0312	23	Mean of three experiments.
0.0625,	0.0159	20	Mean of one experiment.
0.0312,	0.0079	20	Mean of three experiments.
0.0156,	0.0039	40	Mean of three experiments.

The urediniospores of *P. Antirrhini* are able to germinate in all the strengths of Bordeaux mixture employed by the writer. They germinate as readily in the mixture containing 1 per cent copper as in the mixture containing only 0.0039 per cent copper. There was a 10 per cent difference in favor of the weaker mixture, but this has no significance when we consider the irregular fluctuations shown by the intermediate strengths. It is probable that at the lesser strength the sprayed slide or leaf offers the maximum surface of solute to the solvent. An increased strength, as 1 per cent copper, means that the particles on the slide or leaf merely overlap each other, and do not offer an increased surface proportional to the added amount of substance. Having found a certain strength of Bordeaux mixture non-toxic to the urediniospores, increasing the strength of the Bordeaux mixture results in no toxic effect.

To confirm the results of the toxicity tests of Bordeaux mixture against *P. Antirrhini*, snapdragon plants all of the same variety were sprayed with Bordeaux mixture 1 : 0.3 containing 1 per cent copper sulfate. After spraying, the plants were allowed to dry, then with other plants of the same variety, not sprayed, were inoculated with snapdragon rust, the urediniospores being applied to the plants in distilled water by means of an atomizer. All inoculated plants, both sprayed and unsprayed, were then placed for twelve hours in an incubator at a constant temperature of 10° C., after which they were placed together in a greenhouse under the same conditions. Fifteen days after inoculation all the plants which had been inoculated were examined and the uredinia on the leaves were counted. The sprayed plants showed on the average two hundred uredinia each, while the unsprayed plants showed on the average two hundred and ten uredinia each; that is, there was an approximately equal amount of infection on the sprayed and unsprayed plants. Bordeaux mixture cannot, therefore, be recommended for the control of snapdragon rust. Peltier (1919) also came to the conclusion that Bordeaux mixture 4–4–50 will not control snapdragon rust.

Continuing the study of the toxicity of Bordeaux mixture to members of the Uredinales, the writer tested the effect of this fungicide on the germination of the urediniospores of carnation rust, *U. Caryophyllinus* (Schrank) Wint. It is realized that growers do not often spray for carnation rust now, being able to control this disease by cultural methods and varietal selection. But Bordeaux mixture has often been recommended for the control of this rust. Bordeaux mixture 1 : 0.3 was used in these tests in various strengths, so as to contain 0.5, 1, 2 and 4 per cent copper sulfate. The method employed was the same as that described for *P. Antirrhini*, except that the spores were germinated at 14° C., which temperature was found by the writer (Doran, 1919) to be the optimum temperature of germination for the urediniospores of *U. Caryophyllinus*. These urediniospores, like those of *P. Antirrhini*, germinated only when in contact with both air and water, spores in the interior of the drop of water never germinating.

The toxicity tests conducted by the writer showed that Bordeaux mixture is not toxic to the urediniospores of *U. Caryophyllinus*, which indicates that the behavior of the urediniospores of *P. Antirrhini* toward this fungicide is not exceptional. If carnation plants sprayed with Bordeaux mixture failed to rust, it must have been due to other adverse conditions, such as temperature, which prevented spore germination and infection.

It would appear from data obtained by others as well as from the results here reported that the Uredinales are much more tolerant of copper than are the Phycomycetes. Melhus (*loc. cit.*) found Bordeaux mixture toxic to *Phytophthora infestans* (Mont.) De Bary at 0.0039 per cent copper sulfate. But the writer did not find Bordeaux mixture toxic to the two members of the Uredinales studied at 4 per cent copper sulfate. It may be that the thick wall of the spore secretes some chemical substance which prevents the copper in the Bordeaux mixture from going into solution.

The literature contains numerous references to the use of copper solutions as a control of diseases produced by members of the Uredinales, but there is a variance of opinion as to the effectiveness of copper on rust diseases.

The experiments performed by earlier investigators were mostly of the field rather than the laboratory type. Dudley (1890) recommended a saturated solution of potassium permanganate as a control of hollyhock rust. Maynard (1893) found Bordeaux mixture to give good results as a control of carnation rust. Hitchcock and Carleton (1893) found the spores of *P. graminis* Pers. able to germinate in solutions of thirty chemical compounds of various strengths, including 0.1 per cent solutions of mercuric chloride, copper acetate, potassium bichromate, potassium cyanide, acetic acid and sulfuric acid. Pammel (1893) attempted to control rusts on oats and wheat by spraying with Bordeaux mixture, but found no appreciable difference in the amount of the disease on the sprayed and unsprayed plants. Stuart (1894) found that Bordeaux mixture of standard and half strength solutions gave best results in the control of carnation rust. Bailey and Lodeman (1895) sprayed carnations with a mixture of Bordeaux mixture and soap. They also used a mixture of copper chloride, lime and soap. They concluded that the copper fungicides were most efficient in the control of carnation rust. Stewart (1896) recommended spraying with weak copper sulfate for the control of carnation rust. He found that the spores of *U. Caryophyllinus* can germinate in a copper sulfate solution containing 0.0025 per cent copper, and that there is slight germination in copper sulfate solutions containing as much as 0.083 per cent copper. He found these spores unable to germinate in 0.033 per cent solution of potassium sulfide. This investigator found that if copper sulfate is applied to carnation cuttings in a solution strong enough to control the rust the plants are injured. He found that Bordeaux mixture would not control carnation rust, and recommended spraying carnations with a 0.56 per cent copper sulfate solution, or with a 0.78 per cent solution of potassium sulfide. Sturgis (1896) recommended potassium permanganate for the control of hollyhock rust. Halstead (1897) sprayed hollyhocks with Bordeaux mixture, and found rust on all the check plots, while but one sprayed plot showed any rust. Kinney (1897) sprayed carnations with Bordeaux mixture, and concluded that this treatment did not control the rust. Abbey (1898) recommends Bordeaux mixture as an efficient fungicide in the control of chrysanthemum rust.

A survey of the literature on rust control by fungicides is not very helpful. Some of the statements made are misleading and few are very convincing; for instance, it is hard to see how potassium permanganate could be of any great value in combating a rust. Potassium permanganate destroys organisms by oxidizing them, and if in contact with oxidizable material it very soon loses its power; hence it would be of no avail against spores which subsequently fell upon the sprayed surface. Some investigators found Bordeaux mixture efficient and some found it inefficient as a fungicide for the control of rust. The narrow range of temperature in which the spores can germinate may have been exceeded, and the credit for no germination given to the fungicide instead of to a faulty temperature which reduces or prevents germination. But the literature does indicate that the rusts are very resistant to fungicides in general, especially to copper fungicides.

Sulfur Fungicides.

Dusting with sulfur has been used successfully as a control of *P. Asparagi* Dec. (Smith, 1905 and 1906). Butler (1917) described a sulfur dust control for rust of snapdragon. Stone (1917) recommended for the control of snapdragon rust that plants be dusted with powdered sulfur every ten days, or sprayed with lime-sulfur 1 : 35.

The writer began his study of the toxicity of sulfur by testing the toxicity of sulfur applied in water. Powdered sulfur, washed and freed of sulfur dioxide, was added to drops of distilled water in which urediniospores of *P. Antirrhini* were placed. These spores in water with sulfur and the checks (spores in water without sulfur) were then placed at a temperature of 10° C. Subsequent examination showed that the spores in water with sulfur germinated quite as well as the spores in water without sulfur. This result is not surprising, for sulfur, being insoluble, would hardly be expected to have a fungicidal effect when applied in water. This result agrees with that of Melhus (*loc. cit.*), who found that the spores of *Phytophthora infestans* germinated as easily in water containing sulfur as in pure water.

The toxicity of dry sulfur to urediniospores of *P. Antirrhini* was next determined. Dry urediniospores were placed on slides and dusted with powdered sulfur. These were then put into desiccators and kept for three and one-half hours, some at a temperature of 12° C. and some at a temperature of 21° C., then placed in drops of distilled water and set away for twelve hours at their optimum temperature for germination, 10° C. They were accompanied by unsulfured spores as checks. The following table shows the relative germination of the spores sulfured at 12° C., and those sulfured at 21° C.: —

TABLE 11. *Effect of Dry Sulfur and Temperature of Application on the Germination of the Urediniospores.*

Germination of Spores exposed to Sulfur Three and One-Half Hours at the Temperatures stated. (Relative to Check, 100.)		Remarks.
12° C.	21° C.	
90.1	0	Mean of ten experiments.

It is thus shown that spores dusted with powdered sulfur and kept three and one-half hours at a temperature of 21° C. do not germinate. Spores similarly treated, but kept during the sulfuring at a lower temperature, 12° C., germinate as well as unsulfured spores. Sulfur at the lower temperature is comparatively inert, but at the higher temperature it reacts slowly with the oxygen of the air to form sulfur dioxide.

The experiment just described shows that sulfur as such is not toxic to the spores of this fungus. It is rather the sulfur dioxide generated by the exposure of dry sulfur to warm air that is toxic to the spores of the fungus. The more surface a substance exposes the more rapidly it reacts chemically. Hence the necessity of having finely divided, that is, finely powdered, sulfur rather than a coarser grade.

As a continuation of this experiment urediniospores were taken from snapdragon plants which had been dusted with powdered sulfur at a temperature not less than 21° C. These plants bore many spore pustules, and the fungus was to all appearances vigorous. But these spores failed to germinate when placed under optimum conditions for germination.

Fungine is a commercial preparation which has been used by some growers in their attempts to control snapdragon rust. As stated by the makers, it contains potassium polysulfide 6 per cent, and potassium thiosulfate 4 per cent. The writer tested the toxicity of this preparation to the spores of *U. Caryophyllinus* and of *P. Antirrhini* at various strengths and at the strength recommended by the makers. Fungine proved toxic to the spores of both of these fungi.

Table 12. — *Effect of Various Strengths of Fungine on the Germination of the Urediniospores of P. Antirrhini and of U. Caryophyllinus.*

Strength of Solution (Per Cent Thiosulfate).	Germination relative to Check, 100.		Remarks.
	P. Antirrhini.	U. Caryophyllinus.	
0.25, ...	0	0	Mean of four experiments.
0.50, ...	0	0	Mean of four experiments.
1.0, ...	0	0	Mean of four experiments.

Fungine, though toxic to the spores of these fungi, has certain disadvantages. It is no more efficient than powdered sulfur, but it costs more than the sulfur, and the sulfur dust reaches parts of the plant which a liquid spray would not. Fungine when sprayed on a slide or leaf has a physical character resembling a soap film, and this soapiness makes it wash off the leaf too easily, which may in part account for Peltier's conclusion (*loc. cit.*) that snapdragon rust in the field cannot be controlled by Fungine.

Temperature Regulation.

It has been shown that the urediniospores of *P. Antirrhini* cannot germinate below 5° C. nor above 20° C., and that they germinate best at 10° C. (50° F.); 50° F. is the night temperature at which the snapdragon is usually grown under glass; it is frequently grown in the house with carnations. This temperature results in a maximum amount of rust on the snapdragon. The carnation, on the other hand, is grown at a night temperature of 4° C. below the optimum for germination of the spores of carnation rust, and this may in part explain why carnation rust is so much less serious than snapdragon rust. Day temperatures of the houses are not important in the study of snapdragon rust, for those temperatures are usually too high for germination of the urediniospores, so we may consider infection as taking place only in the night.

If growers would raise or lower the night temperature of the snapdragon house to 52° F. or 48° F., the rust would decrease in amount about 50 per cent. This is indicated in the constant curve showing the relation between temperature and germination. It must be remembered that this temperature change prevents infections and prevents the spread of the disease, but it does not kill the spores. So if the temperature approaches the germination optimum even for a few hours, the disease may break out again. Rise of temperature as a control is further considered under treatment with sulfur. Growers may object to raising the temperature very much above 50° F. because of the danger of shortening the blossom spikes, but a rise of even two or three degrees will check the rust, and is not likely to diminish the value of the blossom spikes.

Selection of Resistant Varieties.

Forty-six varieties of snapdragon have been observed by the writer, and their relative resistance to *P. antirrhini* has been determined. The most susceptible varieties are Half Dwarf, Rose Queen, Fiery Belt, Crimson Queen Victoria, Ruby, Carter's Pink, Delicate Rose, Dwarf Golden Queen, Sulphur Yellow, Venus, Carter's Gold Crest and Chamois. It is recommended that the above varieties be not grown at all. The most resistant varieties are Queen of the North, Pure White, Rose Dore, Giant White, Crimson, Giant Blood Red, Giant Yellow, Striped Varieties, Hephætos, Phelp's White, White Queen Victoria, Firebrand and Mont Blanc. It is recommended that outdoor gardeners confine themselves principally to these varieties. These varieties, while not absolutely resistant, are the nearest approach to it among snapdragons. Florists grow only a few varieties, as a rule, notably, Keystone, Silver Pink, Buxton's Pink, Phelp's White and Nelrose. None of these varieties is really resistant. Florists can control this disease less by the selection of resistant varieties than can outdoor gardeners, but the florist can propagate from resistant individuals if any appear, and meanwhile safeguard his crop by the sulfur treatment.

Regulation of Moisture.

It has been shown that although temperature does not kill the urediniospores of *P. Antirrhini*, six weeks of drying does kill them. The teliospore may be eliminated as a factor; and as the urediniospores cannot germinate after six weeks of drying, there is no danger of the disease being transmitted on dry seed; also it is evidently impossible for urediniospores to live from season to season in a greenhouse if the snapdragons are removed and the house deprived of water for a period of at least eight weeks. A case of this kind has recently come to the attention of the writer. A house of snapdragons was severely attacked by rust last year. This year mignonette is being grown in the space occupied by last year's rusted snapdragons. Among the mignonette plants are many seedling snapdragons, the descendants of the rusted plants, but these seedlings are absolutely clean and free from rust. Here we have a case of seed from infected plants producing seedlings free from disease, although they are growing in the space occupied by the diseased plants the previous year. Apparently their only protection is the drying out of the urediniospores.

Use of Fungicides.

The copper salts and copper mixtures, the toxicity of which to *P. Antirrhini* was tested in the laboratory, are copper sulfate, cuprammonium sulfate (Eau celeste), Bordeaux mixture (cupric sulfate to calcium oxide in the ratio of 1 to 0.3 present), and Hammond's Copper Solution. It is shown that Bordeaux mixture is absolutely useless for the control of this disease, for at no strength suitable for use on plants does it prevent germination, and sprayed plants when inoculated develop quite as much rust as plants similarly inoculated but not sprayed. The toxic constituent of Bordeaux mixture is copper sulfate, and this used alone has a toxic effect on the spores of *P. Antirrhini*, but in principle does not dissolve with sufficient rapidity to be efficient against either *P. Antirrhini* or *U. Caryophyllinus*.

Copper sulfate solution, 0.25 per cent copper, is toxic to the urediniospores of *P. Antirrhini*, but the use of this strength of copper sulfate on snapdragon is precluded because of its toxic effect on the foliage. Cuprammonium sulfate (Eau celeste) is toxic to the urediniospores of *P. Antirrhini* at 0.0625 per cent copper, but this strength of Eau celeste is liable to result in a toxic action to the foliage of snapdragon, unless the foliage can dry off in less than one hour. This nearly precludes the use of Eau celeste on thick crowded plants, for the bottom foliage would dry off too slowly. Eau celeste can be used only when the principle toxic to the foliage can be volatilized by rapid drying. Hammond's Copper Solution is not toxic to the urediniospores of *P. Antirrhini*, and is therefore of no use for the control of snapdragon rust.

A method for the control of snapdragon rust by dusting of the plants with sulfur has been described by Dr. O. R. Butler (1917). During the winter of 1916–17 the writer inspected, at intervals of two weeks, greenhouses of snapdragon which had been thus treated. When the treatment began the plants were in very bad shape, leaves and stems were fairly covered with rust pustules. The first thing done was to cut out those shoots so badly infected as to be hopeless. Many of them were girdled and dying. The sulfur used was obtained from the Union Sulphur Company and from Corona Chemical Company. It is powdered finely enough to pass through a sieve having 40,000 holes to the square inch. It was applied with a good bellows that filled the air of the greenhouse with dust, which settled as a thin even film on the foliage. For plants 10 inches high, 4 ounces of sulfur were applied to 150 square feet of bench. The sulfuring was repeated at intervals of two to three weeks, as necessitated by new growth of plants. Exposed blossoms were injured, but there was no injury to the leaves. For two days after sulfuring the night temperature was kept between 60° F. and 70° F. Spores from these sulfured plants were tested from time to time and were uniformly unable to germinate. The mycelium in the plant remained alive, and occasionally produced new sori near the old ones. But new infections were impossible, and the spread of the disease was checked. In one case some young plants which had been sulfured became infected, but the explanation was soon found. They had been grown since sulfuring at a temperature not over 50° F. To be successful, the sulfur must be accompanied by some rise of temperature.

Fungine, a potassium polysulfide preparation, is toxic to the urediniospores of *P. Antirrhini*. It controls snapdragon rust under glass if applied to the plant frequently, but its use is not recommended, for it has no advantages over powdered sulfur, while it costs more and cannot be applied as thoroughly as a dust.

Summary of Control Measures.

Many of the experiments already described contain suggestions as to the control of snapdragon rust. They may be summed up as follows: —

1. There is only very slight chance of rust entering a house on the seeds. The urediniospores would not live on the seeds. Teliospores are not formed till after seed is harvested, and are of no use to the fungus when formed.

2. A house which has contained snapdragon rust should not be used for snapdragons the following year if any plants have remained alive during the interim, nor unless the house has been dried out.

3. Cuttings should not be taken from a bench showing rust. If such cuttings must be used, dust them with powdered sulfur, and give them a high temperature for a few nights.

4. Varieties showing resistance to rust should be selected. The list of varieties showing relative susceptibility should be of assistance here.

5. Water should be kept off snapdragon foliage. In watering, only the soil should be wet. If syringing becomes necessary it should be done on a sunny morning so that the foliage will dry off quickly.

6. Insects should be kept down; they serve to spread the rust. But cyanide must be used carefully, as snapdragons are easily injured by it.

7. If rust appears the plants should be dusted with finely powdered sulfur. If only a few isolated leaves are infected they should be removed by hand picking. The sulfur should be applied with a good bellows that will throw clouds of dust. The temperature should be kept up for a few nights. (For more detail on sulfuring, see the article by Dr. O. R. Butler, 1917.)

8. A solution of cuprammonium sulfate containing 0.065 per cent copper will control the fungus, but because of its toxic effect on the foliage it can be used with safety only when the sprayed foliage will dry within one hour.

9. Bordeaux mixture is absolutely ineffective.

10. If rust appears the temperature should be run up to 60° F. at night for a few nights, till the rust has been placed under control by sulfuring or hand picking. It should be borne in mind that 50° F. is the temperature most favorable to the fungus.

Summary.

Puccinia Antirrhini Diet. and Holw. is known to occur only on *Antirrhinum majus*.

This rust is the most serious disease of snapdragons under glass, and is second in importance to anthracnose on snapdragons out of doors.

The urediniospores germinate moderately well with an optimum temperature of 10° C.; the teliospores have not been germinated.

Dry urediniospores do not retain the power of germination more than six weeks.

No varieties of snapdragon are absolutely resistant to the parasite, but some are relatively resistant. The varietal resistance is dependent on the relative number of stomata per unit area of leaf surface.

The urediniospores are disseminated by cuttings, insects, water and wind.

A 0.25 per cent solution of copper sulfate is toxic to the urediniospores of *P. Antirrhini*.

A 0.25 per cent solution of cuprammonium sulfate is toxic to the urediniospores of *P. Antirrhini*.

Bordeaux mixture is not toxic to the urediniospores of *P. Antirrhini*.

The SO_2 generated by dry sulfur at a temperature of 21° C. is toxic to the urediniospores of *P. Antirrhini*.

The method of control recommended consists in growing resistant varieties, controlling cultural conditions carefully, dusting with powdered sulfur at a temperature of 70° F., and keeping the night temperature of the snapdragon house above 52° F. or below 48° F.

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BULLETIN No. 203.

DEPARTMENT OF BOTANY.

TOBACCO WILDFIRE.

PRELIMINARY REPORT OF INVESTIGATIONS.

BY G. H. CHAPMAN AND P. J. ANDERSON.

INTRODUCTION.

Wildfire is the name of a bacterial disease of tobacco which was first reported in 1916 in North Carolina. It may possibly have been present in previous years, but was not noted until Wolf and Foster (4) described the trouble in that year, when it caused losses in some fields. Since 1916 it has been found in a number of the tobacco sections of the country, more particularly in Kentucky, Virginia and South Carolina. It was first noted in Connecticut in 1919, but was not reported in any amount until 1920, when Dr. Clinton of the Connecticut Agricultural Experiment Station found it to be serious locally. During the same season it was found in three localities in Massachusetts.

In 1921 a very serious seed-bed infection was reported from both Connecticut and Massachusetts, and at a somewhat later date the disease was also reported from seed-beds in Pennsylvania and Ohio.[1] The disease has not been serious in the South this year, but in Massachusetts and Connecticut there was not only a wide seed-bed distribution, but also severe infection, particularly in the broadleaf, where diseased plants were set in the field. It is estimated that in Massachusetts approximately 20 per cent of the seed-beds, including those of all types of tobacco, had more or less wildfire infection. In some cases there was only a slight infection, and in others up to 90 per cent of the seedlings were infected.

The importance of the disease to the tobacco industry is great because leaves which are badly spotted are practically valueless; and furthermore, in the fields the infection works from the bottom of the plant towards the top, as a rule, and the best-quality leaves are the ones first infected.

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[1] Plant Disease Bulletin, 5: 19, 37. 1921.

Last year, when to the best of our knowledge the disease appeared in rather widely separated localities in Massachusetts, it was felt that the spread might not be rapid, but in 1921 the infection was quite general throughout the State, with apparently local centers of heavy infection, the only beds or sections free from the trouble being those in outlying districts.

Unless the disease is controlled there is no question but that it will become a serious matter and the cause of considerable loss to the tobacco growers. It is apparent from data collected this year that nearly all, if not all, of our field infections originate in the seed-beds; hence the production of healthy seedlings becomes a matter of prime importance.

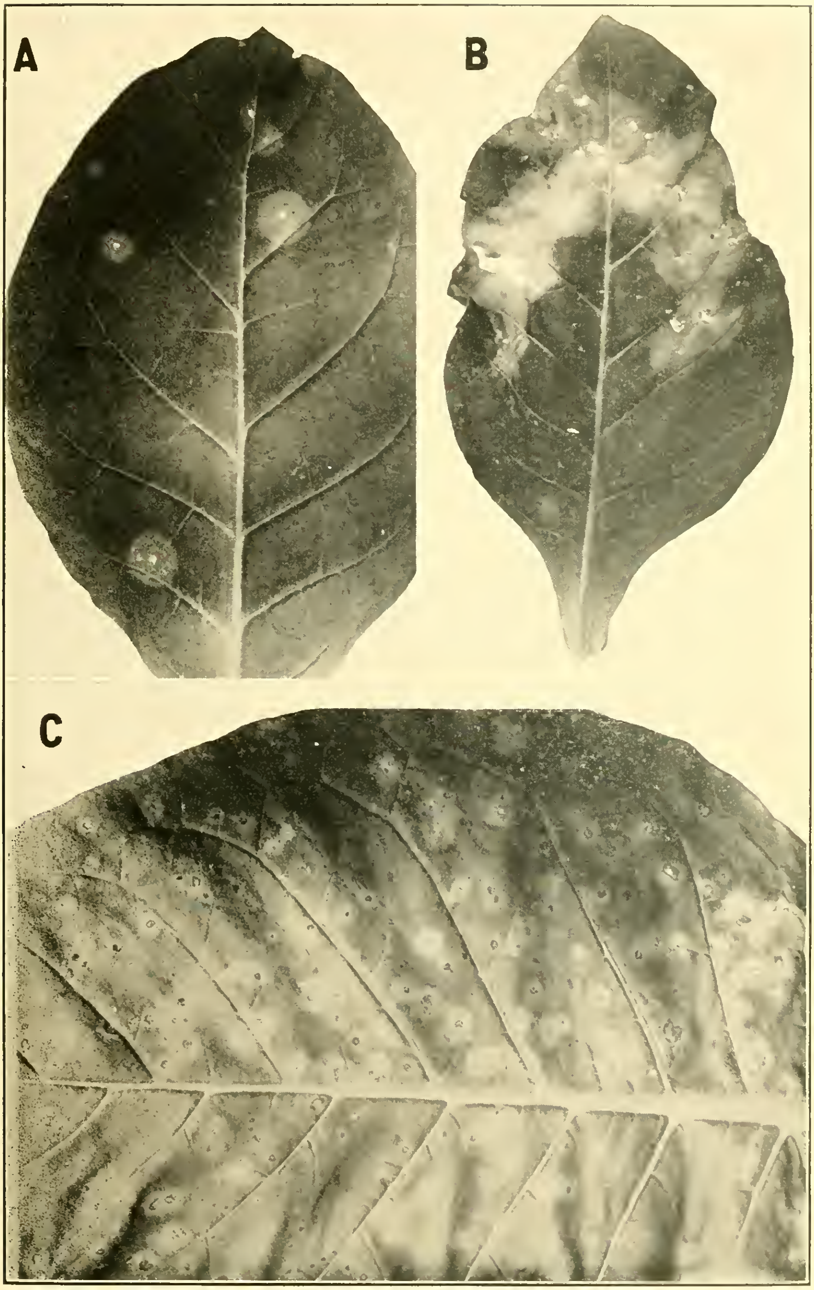
Weather conditions have a great deal to do with the spread of the trouble, as has been shown not only in the South but in Massachusetts as well. But even under favorable conditions timely control measures are necessary to combat the trouble.

It is not known how in 1921 wildfire became so generally distributed throughout the different sections, nor why we apparently had two or three successive infections during the seed-bed period. In order to determine these points, and to find, if possible, some methods of prevention, eradication or control, investigations were begun by the writers in the spring of 1921. These investigations are by no means completed, but sufficient data, especially on seed-bed control, have been secured to warrant a preliminary report.

APPEARANCE OF THE DISEASE.

The symptoms or signs of the disease are prominent and very easily recognized. The spots may be found on the leaves at any stage in the development of the plant from the time the first seed-leaves appear to full maturity. They are sometimes found on the seed-pods, but have not been observed on stalks or roots. They are usually noticed first in the seed-bed. The typical spot on the leaf in its first recognizable stage is a circular chlorotic area, yellowish green, of a lighter color than the surrounding leaf surface, and less than a quarter of an inch in diameter. Within the next twenty-four hours a small brown or whitish dead speck of less than pin-head size marks the center of the lesion which, under conditions favorable for the disease, has now increased to a quarter of an inch or more, is of a more decided yellow color, and forms a prominent halo about the central dead area (Plate I, Fig A). Both the central brown dead spot and the yellow halo now increase in size, and within a few days the affected part may be a half inch or more in diameter. The central brown dead part may or may not be surrounded by a water-soaked translucent band, depending apparently on moisture conditions. In very humid times the entire spot is sometimes soft and water-soaked. The most constant and dependable character is the yellow halo which persists in all stages of development. Any number of spots may occur

PLATE I.



Symptoms of Wildfire.

A. Infection of four days, showing typical halo spots with pinhead centers.
B. Multiple infections coalescing and causing distortion of leaf.
C. Typical infection of leaf in field seven days after heavy rain.

on a single leaf (Plate I, Fig. C), and when numerous they usually run together to produce large irregular dead areas. Frequently, when a leaf is attacked while it is rapidly developing, the affected part becomes distorted and uneven (Plate I, Fig. B). Spots may be located on any part of the leaf, but a great number of them are marginal with a semi-circular halo. During dry weather the dead areas remain intact, but in stormy weather they may be broken out and result in a ragged appearance of the leaf. Severely attacked plants, especially in the seedling stage, may die, but more often the plant continues to grow and is only stunted by the injury or loss of a part of its leaves. In the field the lower leaves are most affected. No lesions are found at the top of the plant on the very young leaves which are just unfolding. Badly affected leaves are practically worthless on the market, as they cannot be used for wrappers or binders.

In the very early seedling stage, when the plants are no larger than the thumb nail, the symptoms may be atypical and not readily recognized as wildfire by the inexperienced. Superficially, affected plants have much the appearance of being attacked by ordinary damping-off. The leaves are usually affected from the margins inward and the lesions are more typical of a wet rot, and in this condition the water-soaked, translucent line is particularly noticeable between the living and dead tissue. Very often the entire leaf is withered, and nothing but the dried midrib is observable. In such plants the stem, however, is usually not affected, and this character differentiates the trouble from the ordinary damping-off, for in the latter disease infection starts in the stem and the entire plant rots down.

CAUSE OF WILDFIRE.

When the disease first came under investigation in North Carolina, Wolf and Foster (4) demonstrated by isolations and inoculations that it is produced by a parasitic species of bacteria which they named *Bacterium tobacum*. In Massachusetts the writers have made numerous isolations from all the types of lesions described above, and have invariably obtained pure cultures of an organism which gave the same cultural tests as described by Wolf and Foster (5). The same organism has never failed to produce the typical disease when healthy plants were inoculated with it from pure cultures.

An individual bacterium of this species is so microscopically small ($3.3 \times 1.2\mu$) that over 7,500 of them placed end to end would form a chain only one inch long. Its body is cylindrical with rounded ends, and two or three times as long as broad. In fresh cultures the organisms may be seen under the microscope actively darting about, the motion being produced by vibrating the long tail-like flagella (1 to 4 in number) which are attached to one end of the body. The body increases in length and divides into two individuals by the process of fission. After repeated division short chains of bacteria may be observed before they break apart.

Life History of the Causal Organism.

Although there is very little to learn about the structure of this very simple organism, there are many things which it is important that we should know about its life history. Control measures can be developed only after determining important life-history facts, such as the manner and place of overwintering, method of entrance to host, methods of spreading in the seed-bed and in the field, and longevity of the organism in various environments. About some of these life-history phases little or nothing is known as yet; concerning others we now have more definite information. It is hoped that experiments now in progress, but not completed at the date of issue of this bulletin, will clear up some of the places in the life history about which we are now ignorant. At this time we can only summarize the progress which has been made up to the present by investigators in other States, and by the writers in Massachusetts.

Infection. — Infection may occur at any stage in the development of the tobacco plant. The bacteria thrive and cause injury by rapid propagation inside the tissues of the leaf. The method by which they pass from outside the leaf through the epidermis into the interior tissue is not yet definitely known. The only openings through which they can pass are the stomates (breathing pores), the hydathodes (openings on the margins of the leaves for the exudation of water), and accidental abrasions or wounds. The writers have frequently demonstrated, however, that visible wounds are not necessary. Healthy plants of various ages have been inoculated by spraying with a suspension of the bacteria in water. Almost without exception infection has resulted, although the most careful examination has failed to reveal any wounds in the leaves. If the stomates were the only avenues of entrance, one would expect a greater percentage of infection when the lower surface of the leaves was inoculated, but the amount of infection has been about the same, irrespective of whether the upper or lower side was inoculated. The rather high percentage of marginal infection points toward the hydathodes as important infection courts. Moisture has an important role to play in infection, although perhaps more important in dissemination. Infection occurs in the field principally during rainy periods. It is not essential that the water should remain on the leaves for any long time. Successful infections are secured by spraying water suspensions on the leaves even when they become dry within a few hours.

Incubation Period. — This period covers the time between the passage of the bacteria into the interior tissues and the appearance of the first symptom of disease. The length of this period as determined by carefully watched experiments at this station is three to eight days. In the field growers usually begin to notice increased infection in five to seven days after a rain, but since the first symptoms are inconspicuous, and the casual observer does not notice the spots until they have been developing for two or three days, this confirms our conclusion as to the length of the period.

According to Wolf and Foster (5) the bacteria at first propagate only between the cells of the leaf. The cells soon begin to collapse, and one finds not only the intercellular spaces, but the cells themselves filled with dense masses of bacteria. Enzymes secreted by the bacteria apparently break down the cell contents, and some of the decomposition products are used as food for further multiplication of the parasites. As the tissue collapses the bacteria either ooze out to the surface or are exposed by rupture of the epidermis.

Dissemination.

This disease was called "wildfire" because of the extreme rapidity with which it spreads. It has been noted by all investigators of the disease and by tobacco growers that rapid spread invariably follows heavy rains. When the rain drops fall on the diseased spots, the bacteria float out into the water and successive drops splash them to other leaves of the same plant or to neighboring plants. If the rain is accompanied by wind the drops are carried farther and the spread is greater to the windward of diseased plants. A number of cases have been observed by the writers where the spread from a single diseased plant or diseased row resulting from wind-driven rain has been carefully followed. Invariably the area of new infection has been from two to ten times as great to windward as to leeward. These two agents (wind and rain) are undoubtedly the most potent of all the factors involved in dissemination. A number of experiments with various agents suspected of disseminating the disease have been conducted at this station and are summarized below.

Splashing Rain. — In order to corroborate field observations, dropping water from a rose nozzle in the greenhouse was allowed to fall onto diseased leaves and then splash to healthy young plants. The splashing was continued for five hours. Wind, insects and all other agents were excluded. Within five days lesions were observed on the plants where the water had splashed. Check plants in the same bed, which were separated from the splashed plants only by a glass partition and which had been splashed with uncontaminated tap water at the same time, remained entirely healthy. The results confirm in every way the conclusion from field observations that this is a very important agent of dissemination.

Wind. — That wind may be important in carrying the infested rain drops to greater distances has been previously mentioned and needs no further demonstration. But on the other hand, it seemed to be important to determine whether wind alone, without rain, could carry the bacteria from a diseased to a healthy plant. Therefore five diseased plants in pots were placed before an electric fan, and twelve healthy potted plants set at distances ranging from three to twenty-four inches, so placed that the air current passed from the diseased to the healthy plants. The fan was turned on for three hours on four successive days, the plants were sprinkled between times and kept under favorable conditions for infection. Since no infection resulted, even after several weeks, it seemed apparent that wind alone cannot spread the disease.

Leaf Contact. — Since in the seed-bed, and to some extent in the field, the leaves of adjacent plants come into contact, it seemed possible that the bacteria might thus pass from a diseased to a healthy plant. In order to determine whether this is possible, two diseased plants in pots were placed under a closed bell jar with two healthy plants in such a position that healthy leaves were in contact with diseased leaves in a natural way without any device for keeping them together. They were not watered, but moisture soon accumulated inside the bell jar. In a second bell jar the same experiment was repeated, but the jar was open at the top except for a thin piece of cheesecloth used to exclude insects. Infections resulted in both cases. There can be no question then but that wildfire may spread by contact. This factor is probably of more importance in seed-bed dissemination than in the field. When plants have been pulled and piled together in boxes or baskets until ready to be set in the field the moisture conditions are very favorable for the spread of the disease to healthy plants. Occasionally such plants are kept thus for days before planting, and, if diseased plants are present, no better opportunity for spreading wildfire by contact could be found.

Handling by Workmen. — Do workmen, in weeding, transplanting, hoeing, plowing and topping help to spread the disease? In order to answer this question diseased leaves were crushed between the fingers and then leaves of a healthy plant drawn through the fingers without rupturing the leaves. The plants were then kept protected under a bell jar. A few of the leaves thus treated developed typical lesions of the disease. Check plants treated in the same way after healthy leaves had been crushed in the hand remained free from disease. There is no doubt, then, that wildfire may be spread by workmen during the ordinary manipulations of the crop. The danger of spread is much greater while the plants are wet, and if there is any disease at all present, all operations while water is on the leaves should be avoided.

Insects. — It would seem almost impossible for insects to work alternately on diseased and healthy leaves without spreading the bacteria. Wolf and Moss (6) state that "flea beetles are to be regarded as carriers of infection, since the wildfire organism has been isolated from individuals which had been feeding on diseased plants." Flea beetles were the most common insects found on tobacco both in seed-bed and field in this State during the present year, and it was suspected that they carried the bacteria. To determine whether such was the case, large numbers of flea beetles were caged with diseased plants; then, after they had fed on these plants for several days, they were transferred to healthy plants, where they riddled the leaves. No wildfire lesions ever developed on these plants. Thinking that possibly the beetles had not eaten from the diseased spots in the infected plants the writers caged another lot in tubes in which only diseased bits of leaves were placed. Most of the diseased pieces were entirely consumed and all of them more or less eaten. The insects were then transferred to cages in which healthy plants were growing. Although numerous holes were eaten through the leaves, no wildfire lesions developed. The flea beetle experiments variously modified were repeated five times, but always with negative results. Wolf and Foster (5) had the same results with thrips. Other insects have not been found on tobacco in sufficient numbers to indicate that they could be the agents of dissemination. From all evidence which has been secured up to the present time we may conclude that insects are of little or no importance in the spread of the disease. This conclusion is also corroborated by a study of field conditions. If insects were responsible, one would expect to find scattered throughout the field plants which had only one or a few infections on the upper leaves, and spread from a single infected plant would be more rapid. But such is not the case. As will be explained below, most of the infections can be traced from the lower leaves, and can be readily explained by splashing and wind-borne rain.

Origin of the Disease in the Seed-beds.

Wildfire makes its first appearance in the seed-beds when the plants are yet very small. It is very essential that we should know the source of the bacteria which start this initial infection. This involves the whole problem of the overwintering of the bacteria. The possibilities are that the bacteria pass the winter on (1) the seed, (2) the chaff with the seed, (3) in the soil, (4) in the sash, frames, covers, etc. Experiments are now in progress to solve this problem by determining the longevity of the bacteria in various environments, but since these experiments have not as yet reached their conclusion, nothing can be stated as demonstrated. Fromme (2) in Virginia believes that the bacteria overwinter with the seed. The fact that infections are not positively known to start in the field from soil which is splashed onto the leaves leads one to suspect that the soil is not the source of early infection in Massachusetts. In North Carolina, however, Wolf and Moss (6) found that soil or the cloth covers which had been used the previous season could serve as carriers in overwintering the bacteria. We expect to have more definite information in regard to this point before next season. When once started in the bed, the bacteria are easily spread by splashing during watering, contact of plants, weeding, etc.

Source of Infection in the Field.

Careful field observations have been made during the past season on the origin of the field infections and the spread in the field. In the vast majority of cases it has been found that the plants came from infested seed-beds, and in all other cases the seed-bed has been suspected, but it has not been possible always to prove that it was the source. Almost always, throughout the season, when a diseased plant was found the spots could also be found on the lower leaves of the same plant which were present when the plant was set out. If not on the same plant, then they could be found on a plant which was very close by. In all the field observations we have seen nothing to indicate any other independent source of the inoculum.

OTHER HOSTS.

Up to the present the causal organism of wildfire has been found actively parasitic only on tobacco. The possibility is not excluded, however, that it may occur on other hosts. Wolf and Foster (5) isolated the organism from spots on cow peas, and were able to produce the typical disease on tobacco with the strain taken from cow peas. Only occasional small spots developed on inoculated cow peas, and they are of the opinion that the organism is not parasitic on this host, but developed only in the weakened tissues about injuries produced by leaf hoppers. They also inoculated bell peppers, potatoes, tomatoes, eggplants, horse nettle and jimson weed but were unable to produce the disease.

The writers have inoculated petunia, eggplant and pokeweed (*Phytolacca decandra*) by spraying them with suspensions of bacteria in water in the same way in which tobacco plants were usually inoculated. Some of the leaves in each case were wounded by punctures with a sterile needle.

Petunia. — Within four days after inoculation typical wildfire lesions appeared about all the punctures and on some of the leaves where no punctures were made. These increased to the usual size and the centers died. Reisolations gave the organism in pure culture, and, when tobacco plants were inoculated from these cultures, wildfire resulted. The tobacco wildfire organism is thus parasitic on the closely related genus Petunia.

Eggplant. — These plants were kept under humid conditions in bell jars. After six days necrotic lesions developed about all the punctures, but none where punctures had not been made. The lesions were 5 to 10 millimeters in diameter. Thus, although the bacteria are able to spread from wounds, apparently they are not actively parasitic on eggplant.

Pokeweed. — After a week a few lesions developed about the punctures and showed the typical broad halo. Parasitism is thus about the same as on eggplant.

Tomato. — While examining a seed-bed of infected tobacco plants at Southwick, the writers found lesions of the same type on some tomato plants which were growing among the diseased tobacco seedlings. Microscopic examination showed bacteria of the same kind in the lesions, and pure cultures were obtained. Tobacco plants inoculated from these cultures developed typical wildfire lesions. The spots on the tomato leaves appeared to have started around injuries of some kind. Undoubtedly, however, the bacteria were able under natural conditions to spread from these wounds into healthy tissue.

Further investigations of host relationships are in progress. Probably the same species of bacteria does not cause a serious disease of any of our common plants, yet it may occur rather commonly in a semi-parasitic inconspicuous condition, and this fact may prove to be of some importance in the dissemination or overwintering of the organism, and thus indirectly, also, in the control of wildfire.

CONTROL.

Necessity of starting with the Seed-bed.

It has been shown that nearly every field infection originates in the seed-bed, and that as yet there is no positive evidence that the disease has originated in the field, at least in Massachusetts. In every case that came to our attention where healthy seedlings were set, no infection was found except that brought in afterward by partial resetting. Therefore it is evident that if the seed-beds can be kept free from disease, the fields will be free from it also. All control measures should start in the seed-bed.

Sterilization of Soil.

It is the practice of many growers to steam sterilize the seed-beds in order to destroy disease-producing organisms and also to kill weed seeds. With regard to liability of wildfire infection, our observations have been that it has made little or no difference whether or not the seed-beds have been sterilized. It is, however, a good practice, and will minimize the chances of infection from material containing the organisms which may have remained in the beds. No precautionary measures should be overlooked; therefore, where it can advantageously be done, it is well to change the location of the seed-beds, particularly if sterilization is not practiced.

Seed Disinfection.

Fromme (2) has found that the organism overwinters on the seed, and has devised a method for the sterilization of seed which is apparently satisfactory, and, if carried out exactly according to the recommendations, will not injure the seed. We have sterilized several lots of seed this year, and in none of them has germination been injured. Some bad results have been reported, but these have resulted from faulty technique. Two of the most important points in seed sterilization are thorough washing out of the formaldehyde and rapid drying of the seed. Fromme in principle recommends for sterilization of seed the following procedure: Soak the seed for fifteen minutes in a solution made by adding one fluid ounce of formaldelyde (commercial strength) to a pint of water. Stir the seed all the time that they are in the solution. At the end of the time cover the pail or jar with cheesecloth and wash in running water, or wash in several changes of water until all trace of formaldehyde odor has disappeared. Spread the seed in a thin layer and dry as rapidly as possible at room temperature. Do not heat during the drying.

This treatment will not eliminate the possibility of the occurrence of the disease in the seed-bed, for some of our seed-bed infection this past season occurred after the plants were well developed, but it will eliminate one source of infection, and if the other recommendations are followed will reduce the chances of infection.

Sterilization of Sash, Cloth Covers, etc.

In the South it has been shown that the covers used on the beds are sometimes a source of infection, and it is recommended as an additional precaution that the sash, covers and side plank be washed or sprayed with a solution of formaldehyde, 1 part to 50 by measure, and dried before being used. So far, in Massachusetts, we have no positive proof that the disease is carried over in this way, but possibly it may be.

Spraying or dusting Plants in the Seed-bed.

Although the bacteria when once inside the tissues of the leaf cannot be destroyed by application of any substance to the surface, the possibility of preventing them from entering in the first place is not precluded. Spraying and dusting experiments were therefore undertaken with the object of covering the leaves with a poisonous coat which would kill the bacteria while on the surface and before they had an opportunity to pass through the epidermis.

A cloth-covered seed-bed 40 feet long and 6 feet wide was divided into 18 equal plots, and the fungicides applied for the first time when the plants were about 1 inch high and again a week later. The substances applied, rates of application and results are indicated in the table below. Four of the plots received no applications and were used as checks for comparison. No infection was present at the time of the first application, but on the following day the entire bed was sprinkled equally with a gallon of water suspension of the bacteria. Five days later infection was noted in abundance on the checks. The beds were inoculated again after the second application of the fungicides, although frequent rains in the meantime were causing satisfactory spread. One week after the second application the plants were all pulled, examined one at a time, and data recorded as to number of infections. At that time the plants were of about the right size for setting in the field. The amount of control is probably indicated more nearly by the number of spots than by the percentage of infected plants. A hand-operated 2-gallon compressed air sprayer was used for applying the liquids, and a D and B No. 100 powder blower, manufactured by the Dust Sprayer Manufacturing Company of Kansas City, Mo., was used for dusting.

Tabulation of Spraying Results.

Spray Material.	Plot Number.	Total Number of Plants.	Number of Diseased Plants.	Per Cent of Plants infected.	Average Per Cent of Infection.	Number of Lesions per Plot.
None,	5	300	196	66.0	48.25	936
None,	2	251	140	55.0		549
None,	16	265	96	36.0		223
None,	12	263	95	36.0		215
Lime-sulfur,	9	298	168	56.0	56.0	562
Sulfur,	18	301	19	6.0	6.0	26
Pyrox,	6	300	5	1.6	4.1	9
Pyrox,	10	270	18	6.7		28
Bordeaux,	1	207	2	1.0	1.25	8
Bordeaux,	14	266	4	1.5		4
Sanders dust,	2	232	2	.8	.55	2
Sanders dust,	17	302	1	.3		1
Bordeaux and lead,	7	300	0	.0	.5	0
Bordeaux and lead,	11	298	3	1.0		8
Pickering,	8	300	1	.3	.35	1
Pickering,	13	256	1	.4		1
NuRexo,	3	300	1	.3	.48	1
NuRexo,	15	300	2	.66		2

Notes on Substances used, and Results.

Lime-sulfur. — The ordinary commercial liquid diluted at the rate of 1 part to 40. Very severe burning of the leaves occurred within an hour after application. Since, in addition, no control was secured, it is apparent that lime-sulfur should never be used.

Pyrox. — A commercial Bordeaux paste (arsenical included) prepared by the Bowker Insecticide Company of Boston. Applied at the dilution of 10 pounds to 50 gallons of water. This fungicide was washed from the leaves by the rain to a greater extent than any of the others.

NuRexo. — A Bordeaux preparation (arsenical included) in form of a powder prepared by the Toledo Rex Spray Company of Toledo, Ohio. Diluted at rate of 8 pounds in 50 gallons of water. Adhered to leaves much better than Pyrox, but not so well as freshly prepared Bordeaux. There was a slight trace of burning, but not serious.

Freshly Prepared Bordeaux Mixture. — The ordinary 4–4–50 formula. This was washed away by rain least of all the substances which were tried, and was still to be found on the leaves after repeated heavy rains. No burning occurred.

Bordeaux Mixture and Lead Arsenate. — The Bordeaux as above, but the powdered arsenical added at the rate of 2 pounds to 50 gallons of water. Some of the leaves were burned. There seems little if any benefit to be derived by addition of the lead arsenate.

Pickering's Lime-water Bordeaux. — The clear limewater and copper sulfate solution were mixed in the proportions recommended by Cook in United States Department of Agriculture Bulletin No. 866. Considerable burning was observed, especially after the first application.

Sulfur Dust. — This remained on the leaves very well. This plot did not seem to grow as well as the others and the plants were "off color." Since the percentage of control was not so high as for some of the others, it is not to be recommended.

Sanders Dust. — A very finely ground lime-copper sulfate dust mixture prepared by Riches Piver & Co. of New York. Spreads well, adheres well and causes no burning. Both this and the sulfur dust were applied while the plants were wet with dew or rain.

Spraying Results by Growers.

Three tobacco growers followed our recommendations and sprayed with Bordeaux mixture or commercial substitutes of the same. No careful counts of results were made, but observations showed good control, and confirmed our results on the station plots.

Conclusions as to Spraying and Dusting.

Lime-sulfur and sulfur dust do not give sufficient control; Pickering's mixture and the Bordeaux with the addition of lead arsenate cause burning; Pyrox gave less control than some of the others and washed from the leaves too easily. There seems to be little choice between freshly prepared Bordeaux mixture, NuRexo and Sanders Dust. The percentage of control is about the same with all, and there is very little injury. The dust can be more quickly and easily applied, and the writers believe that it can be made to more nearly cover the lower surfaces of the leaves. They prefer the dust to the liquid. For those who prefer the liquid the home-made Bordeaux has the advantages of cheapness and better adhesion. NuRexo, as well as other commercial Bordeaux pastes and powders, has the advantage of being already prepared.

These conclusions are based on one year's experiments, and therefore should not be accepted as absolute. The experiments will be repeated for several years before final conclusions are drawn.

Aeration and Watering of Beds.

As a result of observations and experiments conducted during the season, it is recommended that the watering of the beds be done as seldom as possible, as the splashing of the water drops from plant to plant was found to spread the disease rapidly. Most of the beds are watered too much and the humidity is often very high under the sash. Water of condensation dripping from the sash to the plants also appears to be responsible for some spread. The beds should be run as dry and with as much air circulation as possible. This tends to dry off the leaves, and helps reduce the spread of the disease. In many instances where this was practiced after infections were found, spread was much slower than when the beds were closed tightly and very little if any air circulation permitted. Careful attention to this matter will result also in stronger, better plants.

Fertilizer Relations.

While fertilizer materials are not directly responsible for the disease, there is apparently a relation between the rapidity of spread in the seed-bed and the application of excessive amounts of some materials. This was particularly noted in the case of nitrogen. Where excessive amounts of nitrogen were applied to infested beds, the disease was much more serious on the parts so treated than on those sections to which no additional nitrogen was applied. It was also noted that where growers applied potash to infested beds the spread of the trouble was less than on sections of the beds where none was applied. There have been no careful experiments on the relation of fertilization to susceptibility, but it is known that excessive nitrogen applications force rapid succulent plant growth, with little resistance to any change in environment or disease invasion. Potash is said to cause strengthening of the green parts of the plant, and make it stockier and less susceptible to disease and change in environment. This question cannot be considered settled, and experiments are under way to check up on this point as related specifically to wildfire.

Selecting Plants from Disease-free Beds.

Plants from infested seed-beds should never be set in the field, even though the infection is slight. During the past season it was observed that although plants in and around the infected areas were killed out with formaldehyde, some infection, undeveloped at the time, appeared later, and subsequently many of these beds became heavily infected. Many of the lesions are so small and inconspicuous that they escape any but the most careful observation. A single observation of the seed-bed in the early part of the season is not an indication that the beds will remain free from disease. This was shown by the fact that there were two and possibly three recurring epidemics this past spring, the last occurring almost at the end of the setting season. It was the experience of many growers that while the early set plants from their beds showed none of the disease in the field, the late set plants developed the disease, and it was also noted that many of the plants used for restocking showed the trouble even when pulled from the same beds from which the field was set, and that the disease occurred only on these plants.

Relative Susceptibility of Varieties.

In the seed-bed the different varieties of tobacco seem to show no difference in susceptibility to the disease, but under field conditions the spread of the disease seems to be governed somewhat by the manner and type of growth of the variety. Shade Cuban seems to be but little affected with the trouble after setting in the field. Here the protection afforded by the tent undoubtedly has something to do with it, as the rain and wind is broken; also the open habit of growth, with the leaves relatively far apart, minimizes the chances for a rapid spread. The same is true of the Havana to a less extent, the leaves of this variety, also, having an upright habit of growth, and touching but little.

The practice of priming the leaves of the Shade Cuban and some of the Havana is also an important factor in reducing the spread of the disease, as the first priming is made early, and this includes usually the infected leaves. In this way, as will be noted under the subject of removal of diseased leaves, a large amount of field infection probably is prevented. Perhaps Broadleaf suffers most of all the varieties, as, when the leaves get their growth, they droop and touch each other and also leaves of near-by plants, and thus infection occurs more easily.

During this past season a great deal of late infection in the field has been observed, *i.e.*, many fields of Broadleaf showed practically no infection prior to topping, but after a few days, as the plants were maturing, showed a rapid spread of the disease. Cases have been called to the attention of the writers where the typical halo spots were found on all leaves of the plant. During this past season there was a large amount of "rust" on Broadleaf in some sections, and this has been confused by growers and others with true wildfire. The writers wish to point out the possibility that part of this spotting was caused by excess of nitrogen and deficiency of potash, not sufficient in the case of the latter to show symptoms of potash hunger, but enough to cause a rusting. This rusting occurs on some of the tobacco in Carolina, and has been demonstrated to be a result of the above-mentioned conditions; and this *may* be true of some of the spotting of Broadleaf, and possibly the other varieties, since very little potash has been used during the past four or five years. There is, however, no experimental evidence to warrant this statement as a fact so far as our Massachusetts conditions are concerned.

Removal of Diseased Plants or Leaves from the Field.

When the disease has become established in the field, spraying operations are not practicable. The only promising method of control at this stage seems to be the elimination of diseased plants or leaves. If infection in a field is found to be pretty general early in the season, it is perhaps best to remove all the plants and replant from a bed known to be free from the disease, if such can be found. In two fields containing thirty-five acres of tobacco, entire removal and replanting in this way was practiced with complete success. Practically no infection was found in either field at the close of the season. If the infection is light and the season is not far advanced, only the affected plants should be removed and destroyed, and healthy ones from disease-free beds substituted. When a light infection occurs late in the season there is a fair chance of keeping it under control by careful removal of the diseased leaves only. Good control was secured in this manner in a number of fields which came under the writers' observation during the past season.

Working only with Dry Plants.

In the previous pages the connection of water with dissemination and infection has been explained. If wildfire is known to be present and one wishes to keep it under control, obviously all operations should cease when the leaves are wet from dew or rain.

CONDENSED RECOMMENDATIONS FOR CONTROL.

1. Save seed only from disease-free plants.
2. Sterilize seed.
3. Sterilize seed-beds with steam or formaldehyde, or, when the disease has been in beds the previous year, change the location if practicable.
4. Spray or wash sash, plank or cloth with formaldehyde.
5. Spray or dust the beds with a fungicide weekly from the time the plants are the size of the thumb nail until setting is completed.
6. Water beds only sufficiently to keep plants growing. Ventilate thoroughly.
7. Set plants from disease-free beds only.
8. If badly diseased plants are found in the field, remove and destroy them.
9. If infection in the field is light or occurs late in the season, pick and destroy the diseased leaves when they are not wet from dew or rain.
10. As far as possible avoid working in the tobacco when the leaves are wet.

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BULLETIN No. 204.

DEPARTMENT OF CHEMISTRY.

THIRTY YEARS' EXPERIENCE WITH SULFATE OF AMMONIA.

BY F. W. MORSE.

Sulfate of ammonia has been used for many years at the Massachusetts Agricultural Experiment Station in field experiments with fertilizers. Sometimes the effects have been excellent and at other times positive injury to crops has apparently been caused by its use. The object of this bulletin is to show the conditions under which sulfate of ammonia has been used, and to point out the way that seems likely to give favorable results when it is applied as a fertilizer. No attempt is made to show its effect in comparison with the other nitrogenous fertilizers used on adjacent plots in the same field. The comparative results have been reported from year to year in the publications of the Experiment Station, and nitrate of soda has been superior to the sulfate of ammonia in crop production per unit of nitrogen.

In determining the significance of the data herein presented, the following suggestions may be of value: —

1. Sulfate of ammonia as a source of nitrogen was used year after year in a single arbitrary quantity. It is fair to assume that had the application been varied in amount, as indicated by the probable need of nitrogen of the crop to be grown, better average results would have been secured. Present averages include years in which sulfate of ammonia could not have been expected to bring marked response.

2. It is possible, and in fact probable, that to depend on a single source of nitrogen is unsound fertilizer practice. What would have happened had the sulfate of ammonia been combined with other sources of nitrogen is of course a question.

3. The amount of fertilizer nitrogen applied as sulfate of ammonia was in no way dictated by the value of the crop to be grown. This being the case, any computation as to the profits derived from the use of this material is absolutely meaningless. It was not applied on any profit-making basis.

History of Plots.

The plots on which the sulfate of ammonia has been employed were laid out in 1883 as a part of the first experiment field prepared by the late C. A. Goessmann after the founding of the State Agricultural Experiment Station in 1883. During the first six years the field was used as a soil test, and corn was grown every year. In 1889 the plans were rearranged to permit a comparison of standard nitrogenous fertilizers, which has continued to the present time. The experiments have been described with more or less detail in the annual reports of the Experiment Station, under the headings Field A, and Experiments with Nitrogenous Fertilizers. The earlier reports were prepared by the late Director Goessmann,[1] and the later ones by Director W. P. Brooks.[2]

Soil Conditions.

The surface of the field has a slight, uniform slope toward the east and south. The soil and subsoil are a sandy loam classified in the soil survey of the Connecticut Valley as Norfolk, but later reclassified as Merrimac.[3] At a depth of 4 to 5 feet, as shown by the excavation for drains, the field is underlain by the boulder clay of glacial till. The geological formation is that of a river delta,[4] and excavations for buildings in the vicinity of the plots have shown no stratification in the underlying earth, but irregular masses of coarse and fine material so hard and compact as to require constant use of the pick in excavating. Although the surface soil is quite uniform, there is considerable variation in the depth to the till, which possibly causes some of the differences between plots handled uniformly alike.

Fertilizer and Lime Treatment.

The field is laid out in 11 plots of one-tenth acre each, separated from one another by strips 5 feet in width. A drain of 2-inch tile runs lengthwise through the center of each plot at a depth of 3 feet, and empties into a well formed of 24-inch tile, 4 feet deep, at the bottom of which runs the main drain along the eastern border of the field.

The plots compared in this report are numbered 4, 5, 6, 7, 8 and 9. Sulfate of ammonia has been applied to 5, 6 and 8 at the rate of 225 pounds per acre, while 4, 7 and 9 have received no nitrogen since 1882, and probably a number of years preceding that.

During the preliminary soil test, 1883–88, plots 6 and 8 were unfertilized, while 5 received sulfate of ammonia. Since 1889 all the plots have received per acre 80 pounds of available phosphoric acid in superphosphates, and 125 pounds of potash in potash salts. Plots 4 and 5 have

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[1] Mass. Agr. Expt. Sta., Ann. Repts., 1883 to 1896, inclusive.

[2] Mass. Agr. Expt. Sta., Ann. Repts., 1897 to 1917, inclusive.

[3] Soils of the United States. Bul. No. 55, Bureau of Soils, U. S. Dept. Agr., p. 158.

[4] B. K. Emerson. Geology of Old Hampshire County.

received low-grade sulfate of potash-magnesia, while 6, 7, 8 and 9 have had muriate of potash applied to them.

The plots have had applications of lime at irregular intervals. In 1894, plot 8 alone received a small application of air-slaked lime at the rate of 500 pounds per acre, because it had been persistently inferior to all others in production. The lime produced a favorable effect. All the plots were dressed with hydrated lime in 1898 and again in 1905, at the rate of 1 ton per acre each time. The east half of each plot received an application of hydrated lime in 1909 at the rate of 5,000 pounds per acre, and again in 1913 at the rate of 4,000 pounds per acre.

The east half of the field is positively moister than the west half, so that a fair comparison between the yields produced with lime and those without it cannot be made; but the effects of liming on the relations of the plots to each other can be determined.

The arrangement of the plots permits the comparison of yields from the plots treated with sulfate of ammonia with the yields from plots without nitrogen lying directly beside them.

Scheme of Fertilization of Plots.

NORTH.

9.	No nitrogen, superphosphate, muriate of potash.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
8.	Sulfate of ammonia, superphosphate, muriate of potash.		
	Lime.	1894, 1898, 1905.	1894, 1898, 1905, 1909, 1913.
7.	No nitrogen, superphosphate, muriate of potash.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
6.	Sulfate of ammonia, superphosphate, muriate of potash.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
5.	Sulfate of ammonia, superphosphate, sulfate of potash-magnesia.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
4.	No nitrogen, superphosphate, sulfate of potash-magnesia.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.

SOUTH.

Yields on No-nitrogen Plots.

The yields of the plots without nitrogen, 4, 7 and 9, have been closely studied to ascertain whether there were any consistent differences in their production which might be due to variations in soil; but no uniform relations have been found. During the thirty years, 1889–1918, there was but one season, 1892, when the yields of the three were closely alike. Sometimes one plot has been the best and at other times the poorest. Plot 7 has been the highest in twelve years and the lowest in seven, while plot 4 was highest in eleven and lowest in fifteen years; therefore 7 may be a little the best, while 4 has been possibly a bit poorer than 9. But the differences are slight and cannot be used to explain the variations in yields on the plots receiving sulfate of ammonia. Previous to 1910 the divergences between the highest and the lowest yields on these plots without nitrogen were often from 25 to 30 per cent, and even more, while after the somewhat heavy liming in 1909 — though it covered only one-half the area — the divergences were nearly always less than 10 per cent.

Yields on Sulfate of Ammonia Plots.

The yields on the plots which receive sulfate of ammonia have been somewhat erratic, with first one plot and then the other showing marked inferiority to the other two, and also to the adjacent plots which receive no nitrogen. There is an indication from the flow of drainage water that plot 8 may have soil slightly more open in texture than the soil of 5 and 6; otherwise there is no apparent reason for the variations that have occurred in the yields of these plots in different seasons, by which 8 has oftenest been the lowest producer.

Tables of rainfall and crop yields are given on pages 88 and 89. The gross weights of crops for the individual plots are used without division into grain and straw when the cereals are listed. Nitrogen is definitely known to be a promoter of plant growth rather than maturity, hence the total weight per plot is a proper measure of the crop-producing power of a nitrogenous fertilizer.

Crops Grown.

Eight different kinds of crops have been grown in the period of thirty years covered by the tables. Each kind of crop is taken up separately in discussing the comparative yields from the plots with sulfate of ammonia and from those without it.

Corn. — Corn has been grown in five of the seasons included in this summary. The first crop was in the first year of the experiment. Corn had been grown continuously since 1883, and soil conditions had become such that the yield was smaller than in any of the subsequent years; therefore this year will not be considered in the discussion. The four crops to be compared were grown under somewhat varied conditions of soil and previous cropping.

The crop of 1906 followed the 1905 crop of oats and peas when the land was limed. The sulfate of ammonia plots produced about 20 per cent more weight than the plots without nitrogen. In 1911 the corn followed four successive years of hay production, including some clover, and an application of lime over the east half of the plots in the fall of 1909. The yields without nitrogen exceeded those with ammonia by a small amount, between 2 and 3 per cent. Corn was raised again the next year, and the results were changed, the ammonia plots producing about 7 per cent more weight. The spring months of 1911 were dry, also June and July of 1912. In 1918 corn was the last crop of this period. It had been preceded by potatoes in 1917, millet in 1916 and clover in 1915, previous to which (in 1913) the east half of the plots had been heavily limed. The crop from the limed and unlimed areas was harvested separately. In the presence of lime, the ammonia plots produced an increase of 28 per cent over the no-nitrogen plots, while without lime they were slightly inferior to the plots without nitrogen.

TABLE III. — *Average Yield of Corn (Ears and Stover) (Pounds per Acre).*

	1889.	1906.[1]	1911.[2]	1912.	1918.[3]	
					Unlimed.	Limed.
No nitrogen,	4,600	8,940	10,150	9,980	8,680	11,380
Sulfate of ammonia,	4,630	10,690	9,880	10,720	8,420	14,640
Percentage increase,	–	19	–	7	–	28

[1] After oats and peas with lime.
[2] After clover with lime applied to half area.
[3] Last limed in 1913 over half area.

Oats. — Seven crops of oats were grown during the years covered by the experiment. The first crop (1890) followed the continuous corn culture practiced for seven years. The next three crops (1893, 1895, 1897) alternated with crops of soy beans. In 1898 the crop followed the oats of 1897, but the land was limed before seeding at the rate of 2,000 pounds per acre of air-slaked lime, and the oats were sown as a nurse crop for clover. In 1905 oats were combined with field peas and followed a crop of potatoes, and the land was again limed at the rate of 2,000 pounds of air-slaked lime per acre. Up to this point the land had been plowed every year since 1883, except 1899. In 1914 oats were sown as a nurse crop for clover, after three years of tilled crops, — two of corn and one of Japanese millet. The east half of the plots had been limed in 1909 and 1913. The last two crops of oats were cut for hay and the others were permitted to ripen the grain. The rainfall in 1890, 1893 and 1895 had been well distributed during the months of growth, and was about normal in amount.

TABLE I. — *Rainfall in Inches.*

YEAR.	April.	May.	June.	July.	August.	September.	Total for Year.
1889, ...	2.87	4.71	5.01	7.55	**2.35**	**2.36**	40.37
1890, ...	**1.35**	4.56	**1.42**	5.23	4.06	4.86	**39.48**
1891, ...	**1.55**	**1.64**	4.36	4.93	3.43	**1.78**	**34.82**
1892, ...	**.54**	4.73	2.61	3.28	5.23	**1.29**	40.35
1893, ...	**2.20**	3.17	**2.42**	**1.77**	**2.10**	**1.88**	46.94
1894, ...	9.85	2.92	**1.69**	**.99**	**.19**	**2.38**	**32.64**
1895, ...	5.56	**2.07**	2.76	3.87	3.46	5.04	44.46
1896, ...	**1.32**	2.58	2.57	4.96	3.84	5.41	**39.66**
1897, ...	**2.42**	4.38	6.65	14.51[1]	4.29	**1.94**	57.05
1898, ...	3.73	5.61	3.69	4.09	6.85	3.65	53.89
1899, ...	**1.79**	**1.28**	4.13	4.89	**2.00**	7.90	41.49
1900, ...	**1.85**	3.78	3.65	4.67	4.11	3.67	51.67
1901, ...	5.95	6.91	**.87**	3.86	6.14	4.17	49.72
1902, ...	3.31	**2.32**	4.54	4.66	4.65	5.83	46.99
1903, ...	**2.30**	**.48**	7.79	4.64	4.92	**1.66**	45.45
1904, ...	5.73	4.55	5.35	2.62	4.09	5.45	45.30
1905, ...	2.56	**1.28**	2.86	2.63	6.47	6.26	**38.80**
1906, ...	3.25	4.95	2.82	3.45	6.42	2.59	45.45
1907, ...	**1.98**	4.02	**2.36**	2.87	**1.44**	8.74	42.27
1908, ...	**1.97**	4.35	**.76**	3.28	4.27	**1.73**	**30.68**
1909, ...	5.53	3.36	**2.24**	**2.24**	3.79	4.99	**39.12**
1910, ...	3.07	2.67	2.65	**1.90**	4.03	2.86	**36.11**
1911, ...	**1.87**	**1.37**	**2.02**	4.21	5.92	3.41	44.21
1912, ...	3.92	4.34	**.77**	2.61	3.22	2.52	**38.56**
1913, ...	3.30	4.94	**.90**	**1.59**	**2.26**	2.56	**39.50**
1914, ...	6.59	3.56	**2.32**	3.53	5.11	**.52**	41.83
1915, ...	3.99	**1.20**	3.00	9.13	8.28	**1.37**	51.58
1916, ...	3.69	3.21	5.34	6.85	**2.49**	5.08	45.61
1917, ...	**1.83**	4.13	5.27	3.36	7.06	**2.42**	43.56
1918, ...	2.78	**2.47**	4.01	**1.84**	**2.22**	7.00	**37.47**

[1] Eight inches the 13th and 14th.

Black-face type shows a rainfall much less than normal. It may be noted that from 1907 to 1913 there was a period of deficient rainfall, and the soil grew drier and drier each succeeding year. A short period of spring or summer drought during these years was responsible for pronounced ill effects from the sulfate of ammonia, although the liming of one-half the area conceals the injury in the averages. The period following, as a whole, had a high rainfall, and toxic effects from the ammonia salt were not noticeable on the unlimed area. In 1918 another period of low rainfall occurred, running over into the spring of 1919, when corn was particularly affected by the sulfate of ammonia on the unlimed sections of plots 5 and 6, as described in detail toward the end of this bulletin.

TABLE II. — *Crop Yields (Pounds per Plot).*

Year.	Crop.	Plot 4. No Nitrogen.	Plot 5. Sulfate of Ammonia.	Plot 6. Sulfate of Ammonia.	Plot 7. No Nitrogen.	Plot 8. Sulfate of Ammonia.	Plot 9. No Nitrogen.
1889	Corn (ears and stover), . .	381	488	541	525	359[1]	475
1890	Oats (grain and straw), . .	260	360	385	320	220[1]	290
1891[2]	Rye (grain and straw), . .	390	530	400	450	–	425
1892	Soy beans, green, . . .	1,440	1,935	1,970	1,430	1,450[1]	1,460
1893	Oats (grain and straw), . .	590	630	600	550	420[1]	480
1894[3]	Soy beans, green, . . .	405	645	615	480	680	470
1895	Oats (grain and straw), . .	343	550	560	428	450	430
1896	Soy beans, green, . . .	1,130	1,582	1,870	1,240	1,980	1,050
1897	Oats (grain and straw), . .	189	477	372	197	477	205
1898[4]	Oats (grain and straw), . .	136	238	269	167	278	171
1899	Clover hay, ...	325	340	340	342	420	390
1900	Potatoes, ...	1,387	1,343	1,247	1,268	1,215	1,108
1901	Soy beans (seed and straw), .	428	393[1]	485	385	423	382
1902	Potatoes, ...	1,011	1,002	1,218	1,114	978	1,013
1903	Soy beans (seed and straw), .	269	246	183	177	225	125
1904	Potatoes, ...	758	1,059	694	694	876	1,066
1905[4]	Oats and peas (hay), . .	435	565	660	480	690	390
1906	Corn (ears and stover), . .	957	1,048	1,044	850	1,115	875
1907	Clover hay, ...	340	295	222[1]	300	260	260
1908	Clover hay, ...	340	358	215[1]	463	505	465
1909[5]	Clover hay, ...	395	437	420	315	450	375
1910	Hay, ...	640	722	700	675	680[1]	705
1911	Corn (ears and stover), . .	1,047	996[1]	1,010	956	958[1]	1,042
1912	Corn (ears and stover), . .	950	1,056	1,043	1,034	1,118	1,010
1913[5]	Japanese millet (hay), . .	730	1,020	1,120	670	1,220	670
1914	Oats (hay), ...	190	230	290	205	335	200
1915	Clover hay, ...	845	770[1]	835	783	820	800
1916	Japanese millet (seed and straw),	585	580[1]	675	645	675	640
1917	Potatoes, ...	1,890	1,664	1,669	1,459	1,644	1,463
1918	Corn (ears and stover), . .	936	1,045	1,123	1,055	1,291	1,018

[1] Sulfate of ammonia was apparently injurious.

[2] Crop on plot 8 destroyed by insects.

[3] Plot 8 received an application of lime.

[4] All plots limed on their entire area.

[5] The east half of every plot was limed.

Of the plots receiving ammonia, No. 8 made the poorest yield year after year without regard to kind of crop. In 1897 and 1898 the seasons were excessively wet, and plot 8 equaled or exceeded the other plots. It has been mentioned that this plot has appeared to be a little drier than the remainder of the field, which accords with its variable yields in the different seasons.

The sulfate of ammonia was beneficial in each year, but in 1893, a year of well-distributed average rainfall, the plots without nitrogen yielded their maximum crop and nearly equaled the yields of the ammonia plots. In 1897 and 1898 the ammonia produced marked increases in yields under adverse conditions of heavy rainfall and wet soil.

TABLE IV. — *Average Yield of Oats (Grain and Straw) (Pounds per Acre).*

	1890.	1893.	1895.	1897.	1898.[1]	1905.[1]	1914.[1] Unlimed.	1914.[1] Limed.
No nitrogen,	2,900	5,400	4,000	1,970	1,580	4,350[2]	1,420[2]	2,530[2]
Sulfate of ammonia,	3,220	5,500	5,200	4,420	2,620	6,380[2]	2,160[2]	3,530[2]
Percentage increase,	11	2	30	124	65	46	52	39

[1] Limed in 1898 and 1905 over whole area, and in 1909 and 1913 over half area.
[2] Harvested as hay.

Soy Beans. — Five crops of soy beans were grown in this experiment. Three of them (1892, 1894 and 1896) alternated with grain crops and were cut and weighed green. The season of 1894 was extremely dry, with but 9 inches of rain from April 1 to October 1; consequently the yield in this season was much less than in the other two, when the rainfall was about normal. Plot 8 was given a light dressing of lime in 1894, which resulted in maximum yields on this plot in both 1894 and 1896.

The other two crops were grown in 1901 and 1903 and followed potatoes in each case. In 1898 the field had been limed over its entire area. The two crops ripened their seed, and the weights of the combined straw and beans are given. The rainfall was abundant as a whole, but June, 1901, and May, 1903, were each dry months, and may have influenced the yields somewhat.

In the earlier period sulfate of ammonia produced a marked effect on the crops, reaching a maximum of nearly 60 per cent increase in 1896. The crops of the second period were benefited but little by the ammonia. Probably by this time the soil had become naturally inoculated with the soy bean bacteria for fixing nitrogen from the air, for the soy beans grew nearly as well on the plots without nitrogen as on those which received sulfate of ammonia. In 1901 it was recorded that nodules were abundant on the roots.

PLATE I.—CHARACTER OF VEGETATION ON UNLIMED PLOTS, 1920.

Photo. by R. L. Coffin.

With sulfate of ammonia. Yield per acre, 2,620 pounds.

Photo. by R. L. Coffin.

With nitrate of soda. Yield per acre, 4,180 pounds.

PLATE II. — CHARACTER OF VEGETATION ON LIMED PLOTS, 1920.

Photo. by R. L. Coffin.

With sulfate of ammonia. Yield per acre, 6,095 pounds.

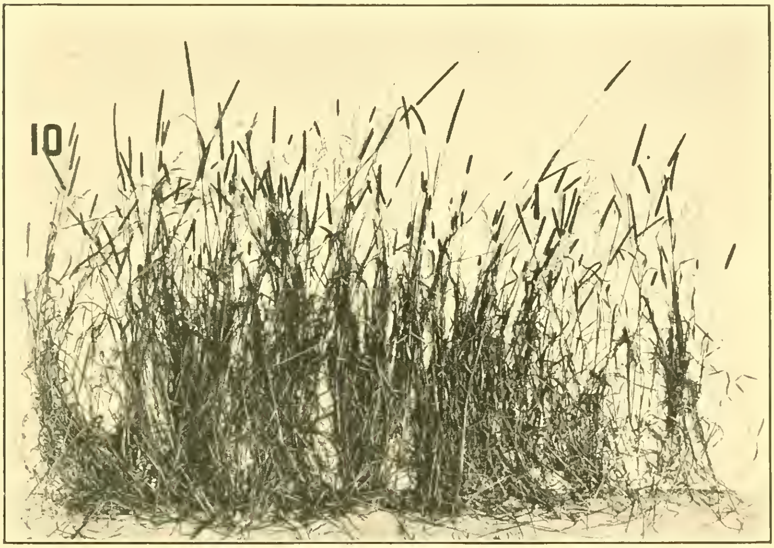

Photo. by R. L. Coffin.

With nitrate of soda. Yield per acre, 6,130 pounds.

TABLE V. — *Average Yield of Soy Beans (Pounds per Acre).*

	1892.[1]	1894.[1]	1896.[1]	1901.[2]	1903.[2]
No nitrogen,	14,430	4,520	11,430	3,980	1,900
Sulfate of ammonia,	17,850	6,470	18,110	4,340	2,180
Percentage increase,	23	43	58	9	14

[1] Weight in green state. [2] Weight dry and ripe.

Potatoes. — Potatoes have been grown four times, three of them in alternate years, 1900, 1902 and 1904, in which period the first crop followed clover and the other two followed soy beans. The soil had been limed in 1898. The seasons were all normal in rainfall. In these three years it is noticeable that the crop steadily diminished year by year on all plots, and in no year was there any appreciable benefit from the sulfate of ammonia; neither can it be said to have injured the crop, as the soil gradually lost the effects of the lime of 1898. It must be considered that either clover or lime had a more positively favorable result than soy beans or sulfate of ammonia.

In 1917 potatoes followed millet, which in turn was preceded by clover in 1915. The east half of each plot had been heavily limed in 1913. On the limed areas there was no advantage from the sulfate of ammonia. On the unlimed areas there was a small gain from its use. The unlimed areas had received no lime since 1905, while the limed had been dressed in 1909 as well as in 1913. Under the conditions of this experiment, which are in no case abnormal, sulfate of ammonia was of little benefit to potatoes.

TABLE VI. — *Average Yield of Potatoes (Pounds per Acre).*

	1900.[1]	1902.[2]	1904.[2]	1917.[3]	
				Unlimed.	Limed.
No nitrogen,	12,540	10,690	8,390	12,060	20,020
Sulfate of ammonia,	12,680	10,660	8,760	12,900	19,340
Percentage increase,	1	–	4	7	–

[1] After clover. [2] After soy beans. [3] Lime last applied in 1913 over half area.

Grass and Clover. — A hay crop consisting largely of clover has been grown in six of the years, but not in any systematic rotation.

The first crop was red clover in 1899. It had been sown the previous year with oats as a nurse crop, and the land received a dressing of lime over the whole area. The clover was winterkilled somewhat, and was unevenly distributed. There was a small gain on the plots receiving the sulfate of ammonia.

The crop of 1915 was produced under similar conditions. The plots were seeded in the spring of 1914 with oats as a nurse crop. The soil had been heavily limed in 1913 on the east half of the plots, but the west half had received none since 1905. The clover was sown in a mixture with redtop and timothy. After the oats were cut the rainfall was sufficient to start the clover promptly, and it grew faster than the timothy and redtop except on the unlimed parts of the sulfate of ammonia plots, where redtop became the principal crop. No cutting was made that season, and the clover and redtop wintered in perfect condition. The two halves of each plot were harvested and weighed separately. On the unlimed half the clover without nitrogen outyielded the redtop with sulfate of ammonia, but on the limed half the sulfate of ammonia produced about 10 per cent more clover than was produced without it. The rainfall was well distributed during the growing periods of 1899 and 1915.

Four of the clover crops, consisting of alsike clover, were grown in four successive years (1907, 1908, 1909 and 1910) as annual crops. The first crop was sown in the corn in the summer of 1906. It did not winter satisfactorily, and after the hay had been removed in 1907 the land was plowed and reseeded with clover. Conditions repeated themselves in 1908 and again in 1909. In no season was there a good stand of alsike clover, but the vacant spaces filled up with weeds or volunteer grasses. The rainfall in 1906 and 1907 was normal; in 1908, 1909 and 1910 it was continuously below normal, but in general was well distributed, and the soil grew steadily drier. The crop of 1909 was from one-fourth to one-half weeds by actual weights. It was the only year of the four in which the plots receiving sulfate of ammonia considerably exceeded in yield those without nitrogen. In the fall of 1909 the east half of the plots was top-dressed with hydrated lime, and in 1910 the crop consisted of much more timothy than clover, with a slight gain on the ammonia.

TABLE VII. — *Average Yield of Hay (Pounds per Acre).*

	1899.[1]	1907.[1]	1908.[1]	1909.[1]	1910.[2]	1915.[2]	
						Unlimed.	Limed.
No nitrogen,	3,520	3,000	4,230	3,620	6,730	8,130	8,050
Sulfate of ammonia,	3,670	2,590	3,590	4,360	7,010	7,300	8,870
Percentage increase,	4	–	–	20	4	–	10

[1] Lime applied in 1898 and 1905 over whole area.
[2] Lime applied in the fall of 1909 and in 1913 over half area.

Japanese Barnyard Millet. — This has been grown twice and the two crops have been produced under quite different conditions. The first crop was grown in 1913 and followed two successive corn crops. The soil had been limed on the east half of the plots in 1909 and 1913. The millet was cut for hay when the seed had formed but had not filled out. The crop of 1916 was a catch crop. The land had produced an excellent crop of clover the preceding year, and the stubble had been plowed under. Potatoes were planted early in the spring of 1916, but the stand proved too uneven to be satisfactory for the experiment, and the land was plowed and seeded to millet in the early summer. The crop was ripened and cut for seed.

In 1913 continuous tillage with corn for two years had used most of the organic nitrogen in the soil, and the sulfate of ammonia plots yielded 60 per cent more than those without nitrogen. In 1916, when there was a lot of organic nitrogen from the clover stubble, the no-nitrogen plots produced almost as well as those with ammonia.

TABLE VIII. — *Average Yield of Japanese Millet (Pounds per Acre).*

	1913.[1]	1916.[2]
No nitrogen,	6,900	6,230
Sulfate of ammonia,	11,200	6,430
Percentage increase,	62	3

[1] Limed over half area. Crop harvested as hay.
[2] After clover. Crop ripened for seed.

SUMMARY OF RESULTS BY CROPS.

Corn was benefited by the sulfate of ammonia in 1906, 1912 and 1918 where lime was present and the land had not recently been in sod. In 1911, following four years of grass and clover, the ammonia was ineffective. Without lime, on old ground, in 1889 and 1918, ammonia was ineffective.

Oats responded to sulfate of ammonia every year in which they were grown. The crop was least responsive in 1893, which was a season of favorable rainfall, and the plots without nitrogen gave a maximum yield.

Soy beans were benefited by the sulfate of ammonia, but its effectiveness grew less as natural inoculation of the soil developed.

Potatoes received little benefit from the ammonia under the conditions of the experiment.

Clover was discouraged by sulfate of ammonia in the absence of lime. Redtop was benefited by the ammonia without lime. Grasses in general require lime with the sulfate of ammonia.

Japanese millet was much increased by the sulfate of ammonia on old ground; but following clover the ammonia had but little effect.

History of the Plots in 1919 and 1920.

Corn and hay have been produced in the two years succeeding the period that has been included in the tables and summary. In 1919 the plots received an application of ground limestone at the rate of 2,000 pounds per acre. The lime was applied on the north half of each plot, lengthwise of the area, instead of on the east half crosswise of the plots, as heretofore. Plot 6 received no lime at this time, while its duplicate, plot 8, was limed throughout. This rearrangement, it is believed, will lead, as time passes, to a fairer comparison between the results obtained with lime and those without lime.

In the preparation of the preceding tables it was deemed best not to include the crop of 1919, while that of 1920 had not yet been produced. Now it seems proper to place them by themselves and amplify the results already shown.

The crop in 1919 was corn, which was grown as a preliminary step to seeding with grass in the summer. Hay from mixed timothy, redtop and clover was produced in 1920. The rainfall for the two years and the crop yields are tabulated below.

Table IX. — *Crop Yields of 1919 and 1920 (Pounds per Acre).*

	1919. Corn (Ears and Stover).		1920. Hay from Mixed Grasses.	
	Unlimed.	Limed.	Unlimed.	Limed.
No nitrogen,	7,520	8,060	2,760	3,540
Sulfate of ammonia,	8,480	10,120	4,620	6,480
Percentage increase,	12	25	67	83

Table X. — *Rainfall, Seasons of 1919 and 1920.*

	April.	May.	June.	July.	August.	September.	Total for Year.
1919,	**2.37**	6.20	**1.09**	4.17	4.81	4.25	41.42
1920,	4.71	3.65	6.26	**2.06**	3.62	6.74	50.09

The value of lime in conjunction with sulfate of ammonia is well shown in these two crops. Although the ammonia produced an increase without lime, the gain with lime was much greater. The absence of clover from the unlimed areas in 1920 was striking, and redtop was the main crop instead. On unlimed areas, with both corn and grass, sulfate of ammonia showed injurious effects which are discussed later.

Peculiar Effects of Sulfate of Ammonia.

A comparison of the crop yields from the plots receiving sulfate of ammonia with those from the plots without nitrogen reveals some striking extremes in the effects of the ammonia compound on plant growth. The largest percentage of gain produced by the sulfate of ammonia was on oats in the years 1897 and 1898, when rainfall was unusually high and the actual yields were among the lowest of the entire period. There are frequent instances, on the other hand, when the crops on the plots without nitrogen were better than those with sulfate of ammonia, which in some cases appeared to have been positively injurious. These ill effects were irregular, and seldom occurred on all three ammonia plots in one season. A study of the rainfall has shown that these apparently injurious effects occurred in seasons when there was a drought in May or June. Applications of lime have remedied the injurious action, but at the same time have tended to bring up the yields on the plots without nitrogen, so that the percentages of increase due to the ammonia are seldom large.

Examination of the soils from the different plots of Field A has shown that, in the absence of lime, the sulfate of ammonia forms soluble sulfates of manganese, aluminium and iron, sometimes one, sometimes another, and again all three.[1] Any one of these substances, if present in comparatively small amount, has been shown to be poisonous to plants, especially to clover.

The rearrangement of the limed areas in 1919 resulted in four distinct gradations of limed soil, as follows: —

Last limed in 1905, ...	Plots 4, 5, 7, 9, Southwest quarter. Plot 6, West half.
Last limed in 1913, ...	Plots 4, 5, 7, 9, Southeast quarter. Plot 6, East half.
Limed in 1905 and 1919, ...	Plots 4, 5, 7, 9, Northwest quarter. Plot 8, West half.
Limed in 1913 and 1919, ...	Plots 4, 5, 7, 9, Northeast quarter. Plot 8, East half.

In 1919 there was a very striking injury to corn on the long unlimed parts of plots 5 and 6. Injury was not apparent on plot 8, as the entire plot had been limed that spring. The plants were stunted in size; the lower leaves were light colored, reddish and yellowish in streaks, and ultimately turned brown and became dry and brittle. Samples of these leaves were dried and incinerated, and the ash gave a bright greenish blue reaction when fused with sodium carbonate, showing that manganese was present in noticeable amount. This was undoubtedly the cause of the injury.

The field was seeded with a mixture of timothy, redtop and clover in the late summer. The areas long unlimed on plots 5 and 6 were bare of

[1] Ruprecht and Morse. Mass. Agr. Expt. Sta. Bulls. Nos. 161, 165, 176.

vegetation, as the seed either did not germinate or the plantlets soon died. In the spring of 1920 these barren areas were twice reseeded, and finally the redtop grew and developed normally.

In July and in October, 1920, samples of soil were taken from the different sections of plots 5 and 6, the soluble manganese extracted by water, and its weight carefully determined by Mr. C. P. Jones.

TABLE XI. — *Manganese Sulfate in the Surface Soil of Plots 5 and 6.*

[Weight of one acre of soil 6 inches deep assumed to be 1,500,000 pounds.]

PLOT.	Lime Treatment.	Manganese Sulfate (Pounds per Acre).
5, Southwest quarter,	Limed, 1905,	235
5, Southeast quarter,	Limed, 1913,	17
5, Northwest quarter,	Limed, 1905 and 1919,	107
5, Northeast quarter,	Limed, 1913 and 1919,	24
6, West half,	Limed, 1905,	177
6, East half,	Limed, 1913,	19

The application of 225 pounds of sulfate of ammonia is theoretically capable of forming 257 pounds of manganese sulfate. There were found small quantities of aluminium sulfate, but only a trace of iron in the soils that were longest without lime.

The weight of evidence indicates that the injurious results were due to the quantity of manganese sulfate present. The actual concentration of the manganese in the soil solution is mere guesswork, but it is interesting to note that its striking injury occurs in seasons of droughts or following a dry period, while plenty of rainfall appears to remove the poison or to dilute it to a harmless concentration.

The effect of lime in preventing the formation of the manganese sulfate is shown by the marked reduction in the amount found where lime had been used as long ago as 1913. The actual quantities found have much less significance than the wide difference between the amounts where lime is lacking and where it is present.

When lime is applied to prevent the injurious effects of sulfate of ammonia, it should be borne in mind that the lime is not a quickly soluble substance but is very slow to dissolve in water. Hence it must be thoroughly distributed throughout the surface soil so that the sulfate of ammonia is reasonably certain to come in contact with it. Long-continued fertilizer experiments clearly show that soil water has no appreciable movement sideways, and the boundaries between limed and unlimed areas are sharply defined.

An experiment where lime to the amount of four times the calculated chemical equivalent of sulfate of ammonia was applied to a small plot showed that it was not enough two successive seasons. Therefore it is best to apply the lime generously in form of finely ground limestone or the fine hydrated lime, as has been done in Field A.

Comparative Effects of Nitrate of Soda, Sulfate of Ammonia and no Nitrogen.

As stated in the beginning of this bulletin, it was not planned to include the results obtained with other nitrogenous fertilizers, but it has seemed best at this point to present the summary of the comparative effects produced by nitrate of soda and sulfate of ammonia which was last published in 1916,[1] the figures in which were as follows: nitrate of soda, 100; sulfate of ammonia, 88.8; no nitrogen, 73.4. This summary includes all the yields on the respective groups of plots.

It has been shown in the preceding pages that liming the soil produces marked benefit with sulfate of ammonia. Therefore a special summary has been calculated in which the yields for the years 1898, 1899, 1900, 1905 and 1906, when the effects of liming were due to applications over the entire plots, have been combined with those of the limed portions obtained in 1914, 1915, 1917 and 1918. This combination produced the following comparison: nitrate of soda, 100; sulfate of ammonia, 91.6; no nitrogen, 70.

The comparative effects in 1919 and 1920 were: nitrate of soda, 100; sulfate of ammonia, 100; no nitrogen, 70. The improvement in the production by sulfate of ammonia is possibly due to the nature of the crops. Under favorable conditions and in the presence of lime, both corn and timothy respond to sulfate of ammonia; and with its long growing season, corn is especially adapted to use the substance.

Conclusions.

Sulfate of ammonia has been effective as a fertilizer when accompanied by an application of lime. In the absence of lime it has sometimes been injurious, due to the formation of soluble compounds of manganese, aluminium and iron. Injury has been greatest in dry periods when the lessened soil moisture becomes more concentrated with soluble salts.

Sulfate of ammonia has been particularly effective on the cereals — corn, oats, rye and millet — when these crops have not followed a clover crop. Potatoes have not been benefited by the sulfate of ammonia in these trials. Soy beans, when uninoculated, responded well to the ammonia; but its effects grew less as the root nodules increased in the later years. Clover has not been much benefited by the sulfate of ammonia, but mixed grasses in 1920 were much increased by it.

In general, the sulfate of ammonia has been about nine-tenths as effective as nitrate of soda, per unit of nitrogen.

[1] Mass. Agr. Expt. Sta., 28th Ann. Rept.

APPENDIX.

Comparative Yields of Sulfate of Ammonia and no Nitrogen, 1889–1918.

Year.	Crop.	No Nitrogen.		Sulfate of Ammonia.	
		Grain (Bushels).	Straw or Fodder (Pounds).	Grain (Bushels).	Straw or Fodder (Pounds).
1889	Corn,	9.4	3,952	20.2	3,213
1890	Oats,	31.3	1,897	33.7	2,137
1891	Rye,	19.3	3,133	22.0	3,415
1892	Soy beans, green,	–	14,430	–	17,850
1893	Oats,	40.5	4,103	28.7	4,580
1894	Soy beans, green,	–	4,520	–	6,470
1895	Oats,	38.4	2,473	45.5	4,077
1896	Soy beans, green,	–	11,430	–	18,110
1897	Oats,	23.0	1,233	37.6	3,217
1898	Oats,	21.4	900	34.9	1,500
1899	Clover hay,	–	3,520	–	3,670
1900	Potatoes,	209.0	–	211 0	–
1901	Soy beans,	27.6	2,383	29.3	2,633
1902	Potatoes,	178.0	–	177.6	–
1903	Soy beans,	12.3	1,192	14.4	1,343
1904	Potatoes,	139.8	–	146.0	–
1905	Oats and peas (hay),	–	4,350	–	6,383
1906	Corn,	46.0	5,717	73.2	5,560
1907	Clover hay,	–	3,000	–	2,590
1908	Clover hay,	–	4,230	–	3,590
1909	Clover hay,	–	3,620	–	4,360
1910	Clover hay,	–	6,730	–	7,010
1911	Corn,	71.7	5,133	74.5	4,666
1912	Corn,	69.5	5,116	79.9	5,133
1913	Japanese millet (hay),	–	6,900	–	11,200
1914	Oats (hay) (unlimed),	–	1,420	–	2,160
1914	Oats (hay) (limed),	–	2,530	–	3,530
1915	Clover hay (unlimed),	–	8,130	–	7,300
1915	Clover hay (limed),	–	8,050	–	8,870
1916	Japanese millet,	28.5	5,234	26.5	5,506
1917	Potatoes (unlimed),	201 0	–	215.0	–
1917	Potatoes (limed),	333.7	–	322.3	–
1918	Corn (unlimed),	28.7	2,433	27.0	2,317
1918	Corn (limed),	31.3	3,400	39.3	4,566

TECHNICAL BULLETIN No. 4.

DEPARTMENT OF BOTANY.

DEVELOPMENT AND PATHOGENESIS OF THE ONION SMUT FUNGUS.[1]

BY P. J. ANDERSON.

I. Introduction.

Onion smut is the most destructive of all onion diseases in New England. In the Connecticut Valley it is probably responsible for more loss to the growers than all the other diseases of this crop combined. Despite the fact that a method of control by the use of formaldehyde has been developed, many fields are now planted to other less profitable crops on account of the ravages of smut; every year sees fields plowed up because smut has so reduced the stand that it is not worth while to tend them; more important in the aggregate, perhaps, is the smaller toll which the disease exacts from each onion grower throughout considerable sections of the valley.

Investigation of the disease with the primary object of finding better methods of control was begun by the Department of Botany of the Massachusetts Agricultural Experiment Station in 1918, and has been continued to date. Since control measures are necessarily conditioned by the normal life history of the pathogene, and since a review of the published research of other investigators showed that the development of the fungus had been inadequately studied, this phase of the problem has been made the subject of no inconsiderable part of the writer's study. Results of the work which deals directly with control are to be presented in another publication. The present paper concerns certain phases of the life cycle of the causal organism (*Urocystis cepulae* Frost) in which it seemed to the writer that further investigation was desirable. Beginning with germination of the spores, the development of the fungus will be followed through its saprophytic stage, infection of the host, distributive stage within the host and final sporogenesis.

[1] This paper embodies the results of preliminary and fundamental work on a project having for its chief aim the control of onion smut. A report on the more practical phases of this project is to be published shortly.

II. Germination of the Spores.

The spore of *Urocystis cepulae* is compound, having one large central fertile cell to the surface of which are attached 15 to 40 smaller hemispherical sterile cells. There are said sometimes to be two fertile cells at the center, but in a three-year study of the fungus the writer does not remember ever having seen a spore with more than one. To conform to the nomenclature of certain other genera of smuts, the entire structure is usually called a spore ball, the peripheral cells being termed pseudospores. Since we have here only one cell capable of germination, it is perhaps better to term the whole structure a spore and then distinguish between fertile and sterile cells. The hemispherical cells are attached to the fertile cell by their flat surfaces, but do not cover it entirely. They stand apart as indicated in Fig. 1 (page 109). The sterile cells are tinted brown, while the central cell is a more solid opaque brown. Sterile cells average 5μ in diameter by 4.25μ in height. The fertile cell is usually spherical, but frequently oval or ovate, averaging about 12μ in diameter. The entire spore averages about 19μ in diameter.

For the germination of most fungous spores it is only necessary to place them when mature in a drop of water, and, after a few hours, or, at most, a few days, the whole process may be watched under the microscope. But for *Urocystis cepulae* the case is not so simple. Germination tests, conducted in the same way in which the writer had brought to germination the spores of many species of fungi, were entirely without result for the onion smut fungus. Apparently there are other essential conditions which had not been obtained in these trials. This preliminary failure led to a thorough search through the literature to find what conditions were essential for the germination of spores of other species of Ustilaginales. It seemed probable that the same conditions which brought about germination in other smuts might also be successfully applied to *Urocystis cepulae*. A condensed summary of the literature of this phase is given below, followed by a description of the experiments with the spores of *Urocystis cepulae*.

Review of the Literature on Essential Conditions for Smut Spore Germination.

The Water Requirement. — No spores will germinate without water in some form, sometimes, to be sure, merely as vapor in a saturated air. In the simplest cases, and, in fact, for the majority of the smut fungi, it is only necessary to immerse the spores, as soon as mature, in a drop of water on a slide, or in a hanging drop. Enough air to satisfy all requirements seems to be present dissolved in the water, or else the spores remain on the surface of the drop. Brefeld (3), in his experiments, germinated the spores in a film of water which adhered to the inside of the walls of flat glass chambers after the bulk of the liquid had drained out. This probably insured greater access to air than where the hanging drop or drop on slide has been used, and this fact should be kept in mind in interpreting his results.

The following species can be germinated in water as soon as mature: *Cintractia densa* McAlp. (11); *C. Sorghi vulgaris* (Tul.) Clint., 12 hours,[1] (11); *Entyloma canescens* (14); *Schizonella melanogramma* D. C. (4); *Sorosporium Reilianum* (Kühn) McAlp., tap water, 17 hours (11); *Tilletia zonata* Bref. (4); *Urocystis occulta* Wallr. (11); *U. primulicola* Magn., 10 hours (14); *U. Violae* Sow. 5 days (4); *Ustilago Avenae* (Pers.) Jens., 6 to 8 hours (8), (11) and others; *U. Boutelouae humulis* Bref. (4); *U. Carbo* Tul., 6 to 10 hours (5); *U. flosculorum*, 5 to 6 hours (7) (he finds that fresh spores germinate most quickly); *U. grandis* Fr., 24 hours (3); *U. longissima* Sow., 3 to 4 hours (3), (7); *U. major* 24 hours (14); *U. Panici glauci* Wallr., 8 days (3); *U. Readeri* Syd. (11); *U. segetum*, 6 to 8 hours, "fresh spores germinate better" (14); *Ust. violacea* Pers. (3) and many others. In the most favorable cases germination begins within two to three hours, while at the other extreme McAlpine (11) mentions species the spores of which did not begin to germinate until they had been in water for several weeks. Where such extreme lengths of time are required, the question arises as to whether this is not really the time required for the weathering process such as takes place when they are kept in damp soil, as in Brefeld's experiments.

Air. — Some spores require only a moist air for germination, and will not germinate at all or only abnormally when immersed in water. Thus Fischer von Waldheim (7) writes: —

> For the normal germination of the different species of Ustilago, a certain quantity of water or moisture is usually necessary. For this purpose, the spores need only be placed in a drop of water, or upon moistened earth, or even merely in an atmosphere kept moist; for instance, under a glass globe placed over a dish of water. But Tilletia and Urocystis germinate only in damp air (for instance, under the glass globe mentioned), and their germinating spores, coming in contact with water, only show abnormal appearances.

In Brefeld's germinating apparatus the spores were never entirely immersed in water, but in the thin film clinging to the chamber walls must have always had a sufficient quantity of air. This probably contributed to his remarkable success in germinating the spores of a very large number of species. McAlpine also found that he was able to secure germination in many cases only by floating the spores in a watch glass over water. Both Brefeld (3) and Fischer von Waldheim (7) mention the fact that the spores of *Tilletia caries* germinate in damp air. Plowright (14) had a similar experience with *Tubercinia trientalis*. McAlpine (11) was able to germinate the spores of *Tilletia Tritici* (Bjerk) Wint. best by keeping them on moist filter paper or blocks of plaster of Paris kept moist by capillary water from a dish in which the blocks were partially immersed. He (11) makes the following interesting observation on the necessity of air for germination of spores of *Ustilago Readeri* Syd.: —

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[1] Figures after the species and not in parentheses indicate the time required for germination to begin after the spores were placed in water. Omission of them indicates that the investigator gave no data as to time required. Numbers in parentheses refer to bibliography on pp. 132 and 133.

Immersed in the liquid they do not germinate as readily as when floating on the surface. Thus, after eighteen hours on one occasion, the spores in the water had failed to germinate, while by simply altering the focus and examining the spores on the surface they were all found, with very few exceptions, to have germinated.

In the descriptions of germination given by the majority of writers there is no way of determining just how much influence the presence of air had.

It seems probable that, in general, the presence of air is essential to the germination of smut spores, but that different species vary in respect to the amount required; some need scarcely any, others must have very free access to air, and there are probably all gradations between these two extremes.

Nutrient Solutions. — Very early in the investigation of smut spore germination it became apparent that the spores of some species could not be germinated merely by placing them in water when mature. Consequently solutions of various substances supposed to have nutritive qualities have been tested for their ability to induce germination. Hallier (6), in 1868, was apparently the first to use such solutions. He used a great many substances such as albumin, starch, milk, sugar solution, etc. Others, since then, have used almost every kind of a salt, acid, or other substance for which one could imagine any germinative influence. One should consult Osner's (13) bulletin on "Leaf Smut of Timothy" to gain some idea of the number of substances that can be used for that purpose. McAlpine (11) seems to have had most success with a hay infusion, although he also used various other solutions. Sugar solutions and decoctions of the host plant have proved fairly successful.

The nutritive solution which has been used most extensively and probably most successfully is the "nährlösung," a sterilized aqueous decoction of horse dung which was employed first by Brefeld (3, 4). In this "nährlösung" he was able to bring to germination the spores of many species which showed no sign of germination in water, *e.g.*, *Cintractia spinificis* (Ludw.) McAlp. (McAlpine (11) also confirmed Brefeld's results), *Doassansia Limosellae* Kunze, *Ustilago Andropogonis tuberculati* Bref., *Ust. Arundinellae* Bref., *Ust. Coicis* Bref., *Ust. Cynadontis* Hem., *Ust. Ischdemi* Fckl., *Ust. major* Schroet., *Ust. Panici leucophaei* Bref., and *Ust. Tulasnei* Kühn. Other species, *e.g.*, *Ust. Maydis*, which gave scanty or only occasional germination in water, germinated to almost 100 per cent in this "nährlösung." In almost every case the growth and size of the germ tube (promycelium) was increased; and frequently sporidia were produced in this nutritive solution where none at all were developed in water. On the whole, however, it should be kept in mind that in by far the majority of cases the function of the nutritive solution was to bring the germling to complete development after it had started, rather than to cause it to start in the first place. Only in the case of the comparatively few species mentioned above did he fail to get some germination in water also, and very commonly the percentage of germination was as high in water as in "nährlösung." On the other hand, he found that *Tilletia Tritici* would not germinate at all in nutritive solution, but could be germinated easily in water.

His experiments with nutritive solutions led Brefeld to believe that smut spores in the soil are brought to germination and further development through the influence of manure which has been used to fertilize the soil. On this theory he explains the common observation of German farmers that cereal smuts are more destructive on freshly manured fields.

Host Stimulus. — One might expect that some stimulus from the host plant would be necessary for germination, and consequently that a decoction from the host, or the presence of bits of it in the germinative medium, would be necessary for starting germination. Although such host decoctions have been successfully used, we find in the literature no instance in which they furnished the only conditions under which the spores would germinate. There seems, then, to be no evidence to indicate that a smut spore must be in close proximity to, or in actual contact with, its host before it will germinate.

Period of Rest. — But, even with the aid of nutritive solutions, and all other conditions which have been tried, there is a considerable number of species, the spores of which cannot be brought to germination immediately after maturity. For these species, a period of "rest" is necessary during which they must be exposed to certain natural conditions which operate in some way to bring them into the proper condition for germination. For our knowledge of this phase of the problem we are indebted, above all, to Brefeld, and we cannot present it better than by quoting from his summary of it ((4), page 128):[1] —

> Only a part of these forms germinate at once even in nutrient solution, more rarely in water; many will not germinate at all, but must be made capable of germination by special methods. . . . The spores of many species are so adapted in their time of germination that they do not proceed at once, but only after passing through a shorter or longer resting period. In cases of this kind one has only to wait until after the expiration of the resting period in order to bring them to germination. But one would often wait long and in vain, if he only kept the spores dry in the house. Under these circumstances, the external influences are not brought to bear, which operate in nature during the period of rest, and which must operate in order to bring about those changes on which the initiation of germination depends. For the most part, when simply kept dry the spores die without germinating, except in a few cases, as, for example, the corn smut, . . . but even here germination is always incomplete. It is necessary to obtain the conditions which in nature operate on the spores and influence them to germinate, if one wishes to succeed in observing germination. The simplest method would be to expose the spores in nature or leave them in their natural habitat and observe from time to time whether germination has begun. But in most cases it is entirely impossible in this way to get and keep the material pure.

He then describes in detail his method of keeping the material in sterilized damp sand in pots in a cool cellar. Then he continues: —

[1] Translated by P. J. Anderson.

> By this method it has been possible to bring to germination most spores which otherwise would not germinate. The length of time required to bring about germination varies greatly. The spores of some species usually germinate after a few months, others after a half or an entire year, others require several years before germination, some even five years. . . . In this methodical way, which is, to be sure, nothing but an imitation of what takes place in nature, ultimately all spores can be induced to germinate. Therefore it can be scientifically proved that the earlier or later germination is only an adaptation, a resting period, which under the natural conditions must be passed through, if the inner and apparently chemical changes are to operate, through which the germination of the spores is slowly prepared and finally made possible.

In this way Brefeld was able to germinate the spores of the following species none of which would germinate when first mature (length of time in moist earth given after each): *Anthracoidea* (*Ustilago*) *Caryces* Bref., over winter; *Anthracoidea subinclusa* Bref., 1 year; *Doassansia Alismatis* Nees, 1 year; *D. Limosellae* Kunze, 1 year; *D. punctiformis* Niesse, more than a year; *D. Sagdlariae* Fckl., over winter; *Melanotaenium cingeus* Bref., 4 years; *Neovossia Barclayana* Bref., 2 years; *Sphacelotheca Hydropiperis* Schum., 6 months; *Tilletia controversa* Kühn, 2 years; *Tilletia decipiens* Pers., 3 years; *Tolyposporium bullatum* Schroet., 9 months; *Tol. Junci* Schroet., 6 months; *Tol. Penicillariae* Bref., 1 year; *Urocystis Anemones* Pers., 6 months; *Ur. Filipendulae* Tul., 1 year; *Ustilago Adoxae* Bref., 1 year; *U. anomola* Kunze, over winter; *U. Bistortarum* D. C., 1 year; *U. Coicis* Bref., 2 years; *U. domestica* Bref., 6 months; *U. Holostei* D., 3 years; *U. utriculosa* Nees. Other writers also have found that for various species, a weathering under natural conditions was necessary in order to secure germination.

Substitution of Nutritive Solution for Weathering Period. — In the case of some species Brefeld believes that the same changes which are ordinarily induced by storage in damp soil for a long period may be induced at once by the use of his "nährlösung." For example, he finds that the corn smut spores when first mature will not germinate in water, but if kept until the following spring they germinate in water. If, however, the freshly matured spores are put in nutritive solution, they germinate overnight almost without exception. He concludes, therefore, that the changes induced by one are the same as those induced by the other, or, in other words, that each may be substituted for the other.

Freezing. — Whether or not freezing has any influence on germination seems never to have been determined. Brefeld makes no mention of freezing, and one infers from his publications that his buried spores were never frozen. Since the spores of practically all species of smuts have been successfully germinated without freezing, it may be safely said that freezing is not a necessary condition of the process.

Essential Conditions for Germination of Urocystis cepulae Spores.

Search through all available literature on the subject revealed only one reference to previous attempts at germination of the spores. Thaxter (18) was unable to germinate fresh spores either in water or in moist air. When, however, the smutted onions were stored until January, then mixed with wet earth and frozen for a week or more, the spores germinated when kept moist in a warm room. They also germinated in an onion decoction. He also made pure cultures in onion decoction from fresh spores and from sporiferous hyphæ, but does not mention germination in this respect. Such, in full, is the extent of our present knowledge of the necessary conditions. The purpose of the writer's experiments was twofold: (1) to duplicate Thaxter's work and (2) to extend the inquiry in order to determine more exactly many points which Thaxter either did not touch or treated insufficiently. The experiments are summarized below.

Fresh Spores in Water. — Spores from a fresh but mature lesion were scattered in a drop of water on a slide kept in a Petri dish with water in the bottom of the dish to prevent evaporation of the drop on the slide. This common and familiar method was used in all the experiments where water or a water solution was tested. Both distilled water and tap water were tried. The spores were examined daily for over two weeks, but no indication of germination was observed. The experiment was repeated many times, and the temperature and light relations were varied in different sets, but always without result. Spores taken from lesions which had been kept dry for a year in the laboratory gave no better results.

Fresh Spores in Soil Water. — A soil extract was made by filling a beaker with good onion soil (taken from a field where smut was abundant), adding water until the soil was saturated and the water was 1 cm. deep on top of it, stirring thoroughly several times and filtering off after several days. Results were the same as with tap and distilled water.

Influence of the Germinating Onion Seed. — These tests were in every way like those described above with water, except that a few germinating onion seeds were placed in each drop in addition to the spores. With one exception, in these tests the spores failed to germinate. On one slide a very few spores germinated in close proximity to the young cotyledon.

Fresh Spores in Soil Decoction. — A mixture of soil and water was cooked for one hour on two successive days in the autoclave at 14 pounds' pressure, filtered, tubed and sterilized. It was hoped that in this way more of the soil substances would be brought into solution, and that they might bring about germination. But, just as in the case of the soil extract, so with this more concentrated soil decoction, there was no germination.

Fresh Spores in Dung Decoction. — This decoction was prepared just as Brefeld prepared his "nährlösung" which he used so successfully on the spores of a large number of species. Fresh spores failed to germinate in it. In these experiments the solution was concentrated. It is possible that if it had been more diluted the results might have been different.

Fresh Spores in Onion Decoction. — This decoction was prepared by boiling a sliced onion in a pint of water for one hour. It was then filtered, tubed and sterilized one-half hour at 15 pounds' pressure. This appears to furnish an excellent medium for the growth of bacteria and fungi, and in working with it every possible precaution must be used to prevent contamination. These organisms grow so fast that they soon obliterate the more slowly germinating smut spores. It was found necessary not only to sterilize, by boiling, the slides, Petri dishes and all instruments used, but also to wash the seedlings from which the spores were taken, first, in mercuric chloride, 1 to 1,000, and then in sterile water, before the lesions were opened. In drops of this decoction some of the spores began to germinate within three days at laboratory temperature. The percentage of germination, however, was always very low. In dozens of slide tests made in this way, not over 25 per cent germination has ever been observed; and in most cases it is lower, averaging 5 to 10 per cent. It is apparent from these tests that there is some substance in the onion which is capable of inducing germination of fresh spores. In the light of other tests described below, however, one would not be justified in concluding that this substance is peculiar to the onion alone.

Fresh Spores in Sugar Solutions. — Sterile solutions of ½, 1, 2, 3, 5, 7 and 10 per cent cane sugar were used just as the onion decoction mentioned above. There was some germination in all of them, but very little in the ½ per cent and the 10 per cent. The highest percentage of germination was in the 2 per cent solution, where 50 per cent of the spores *which were on the surface of the drop* germinated. When spores are mixed with a water solution of any kind, some of them remain on the surface while others sink to the bottom. Only a very small percentage of those which were immersed germinated. Since the spores on the surface are better located for obtaining air, it is apparent that air is an important factor in germination. It is also apparent that sugar is at least one of the substances which may induce germination. Since onions contain a high percentage of cane sugar, it seems probable that this is also the effective element in the onion decoction which induces germination.

Fresh Spores on Onion Decoction Agar. — Onion decoction agar was prepared by adding 2 per cent of agar to the onion decoction. Sterile plates were poured and permitted to become hard. Spores were mixed with onion decoction or water and floated over the surface of the hard agar. After permitting the spores to settle to the bottom the liquid was poured away and the spores were left distributed over the agar. This insured a sufficient quantity of air, and at the same time access to nutrient substances in the agar. The percentage of germination varied with different experiments, but always it was as high as 10 per cent; sometimes 50 per cent. This was found to be the most reliable of all the methods and was largely used. Here also it was noticed for the first time that the spores did not all germinate on the same day, but that there was a progressive germination, new ones starting each day for as long as three weeks, after which the plates had dried too much, or possibly the supply of food had become exhausted.

Fresh Spores on Czapek's Agar, Sugar Potato Agar, etc. — The Czapek's agar contains 3 per cent of cane sugar. Several other agars containing sugar were tried and always with a small percentage of germination, but none higher than on onion decoction agar.

Fresh Spores in Soil Decoction Agar. — After the rôle played by air was determined, it seemed that the writer's previous failure to induce germination in soil decoction might have been due to exclusion of air. Therefore a medium was prepared by adding 2 per cent of agar to the soil decoction. Tests were made as with the onion agar, using soil decoction, however, for floating the spores over the surface. After five days, germination of 1 to 2 per cent was observed. With each day, however, more of them germinated, and this continued for several weeks until the plates became too dry or were exhausted. We may conclude from these experiments that (1) the soil contains all the essential stimulating elements for germination, and (2) not all the spores germinate at once, but there is a progressive preparation.

Fresh Spores on Dung Decoction Agar. — This medium was prepared by adding 2 per cent of agar to the dung decoction mentioned above. Since the soil used in making the soil decoction had been heavily manured during the previous season, it was thought that some element in the manure might furnish the stimulus and a higher percentage of germination would be secured. The percentage of germination in this medium, however, was scarcely as high as for the soil decoction. Here is proof, however, that stable manure contains some substance which is capable of inducing germination.

Effect of Freezing the Spores. — It has been previously mentioned that Thaxter froze smutted mature onions in the soil and then found the spores capable of germination. This experiment was duplicated as nearly as possible by the writer, but he was entirely unable to get the spores free from bacteria and other fungi, and abandoned the method rather than work with contaminated cultures.

An attempt was next made to freeze the spores under sterile conditions. Smutted seedlings were sterilized with mercuric chloride 1 to 1,000, washed in sterile water, and sealed in sterile test tubes with a drop of water in the bottom of each tube. After being exposed for nine days during December, during which there were some light freezes, they were tested in onion decoction. There was a germination of about 2 per cent. In similar tests during January, in which they were frozen solid for ten days or more, buried under the snow in zero weather, the spores were apparently killed. No germination at all was observed, although tried on or in the various media described above. In view of the fact that the mycelium in culture is not killed by freezing, these results are difficult to explain. In a later series of tests smutted seedlings, sterilized on the surface, were buried in sterile soil in test tubes and then frozen out of doors for eight weeks. On onion decoction agar plates, varying percentages of germination were then secured, but it was never as high as for spores which had been kept in damp soil during the same length of time, but not frozen. The conclusion seems warranted that freezing does not kill spores in the soil, but it does not render them more capable of germination, and is not necessary.

Effect of a Period of Rest in Damp Earth. — Seedlings with unopened lesions were sterilized and buried in sterile soil in test tubes. The tubes were then sealed and kept in the laboratory. After two weeks, germination was found to be somewhat higher than in the case of spores from fresh lesions. Tests at the end of four weeks gave 50 per cent germination. At the end of three months the average percentage was not higher, though in individual slides it mounted to about 65 per cent. A higher percentage of germination has not been seen in any test. In removing these seedlings from the damp earth it was constantly noticed that the soil remained clinging to the lesions and could be washed off with difficulty, while it was very easily removed from other parts of the plant. Microscopic examination showed that the soil particles were attached by numerous fungous hyphæ. When these hyphæ were transferred to sterile agar tubes they gave pure cultures of Urocystis. It was not possible to determine whether these hyphæ arose from germination of spores in the sori, from vegetative hyphæ in the seedling or from both. If the spores germinate while still inside the lesion, this may explain why not all the spores taken from the weathered sori germinate; they may have already germinated. This experiment demonstrates clearly one way, at least, in which the smut mycelium gets back into the soil from the diseased plants.

Natural Conditions of Germination. — It is a common impression among laymen that the spore remains dormant in the ground, lying in wait until an onion starts to grow near it, upon which it germinates and infects the onion. Such, however, is apparently not the case. The seedling does not seem to furnish any stimulus which causes the spore to start. Whatever substances are necessary for starting the process are in the soil itself. As soon as the spores are released into the soil — if not before — a few of them germinate; the others become capable of germination gradually, and it seems likely that all of them finally come to germination, but that the period of preparation differs in length for different spores, so that the germination extends over many months and possibly years. This period of preparation may be shortened artificially by the use of certain stimulating substances, such as cane sugar.

The Process of Germination.

Germination begins in three to six days after the spores are placed in the water solutions or on agar plates as previously described. The time varies somewhat with the medium used, and also apparently with other factors which have not been explained. Three days are usually sufficient in onion decoction or onion agar, while on soil decoction agar six days were found necessary.

The first indication of germination is the appearance of a hyaline hemispherical vesicle (Fig. 1, B) on one side of the spore. This is apparently an extrusion from the central fertile cell, but whether it comes out by a rupture of the spore wall or by a regular pore could not be determined. The covering of sterile cells renders exact observation of this point difficult. This vesicle when first observed is of about the same size as one of the sterile cells, and can at first be distinguished from the latter only by the fact that it is hyaline while the sterile cells are brown. During the succeeding stages, however, it increases rapidly in size until it may be almost as large as the spore itself (Fig. 1, K). This hemispherical or subglobose

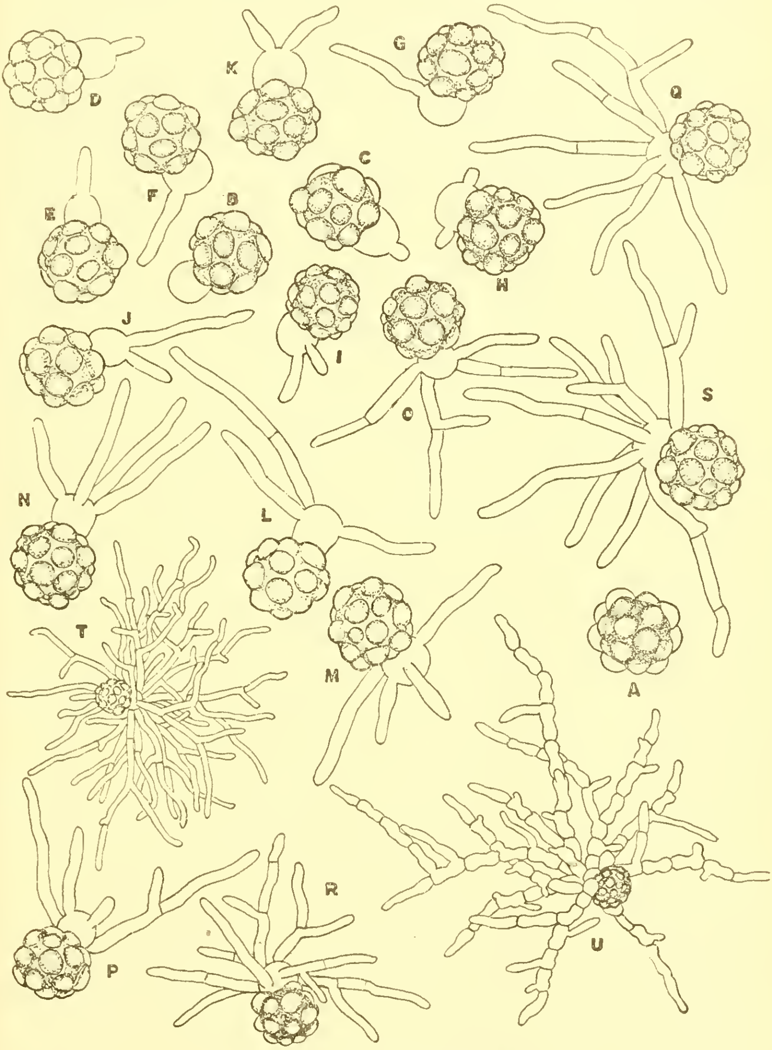


FIG. 1. — Germination of spores.

vesicle corresponds to the promycelium or hemibasidium of other smuts and rusts, and will be so designated. A stout tube grows out from the surface of the promycelium (Fig. 1, C–G) and is quickly followed by others in succession until a whorl of diverging branches is produced (Fig. 1, H–N). The number of branches in the whorl is not constant, neither do they arise simultaneously but usually in succession. None has been observed, however, which showed more than eight branches on a promycelium (Fig. 1, S). These primary branches are 2 to 3μ in diameter, usually somewhat undulating, with broadly rounded tips. They soon become septate, and almost invariably a lateral secondary branch grows out from the top of the cell just below each septum (Fig. 1, O–S). The angle of divergence between the primary and secondary branch is very broad, often approaching a right angle. This manner of branching is characteristic of onion smut mycelium wherever it is found, and is a good diagnostic character. By continued branching, a dense mass of mycelium is developed about the spore, and it becomes increasingly difficult to follow the course of single hyphæ. Fig. 1, T, represents the latest stage in which the separate branches could be followed. On agar plates the older cells lose their dense protoplasmic content, and only the more distant tip cells appear to be alive. In onion decoction, as the hyphæ become older they become more constricted at the septa and the cells rounded in the middle until they appear almost separated from each other, the hypha having somewhat the appearance of a string of beads (Fig. 1, U). Frequently in the older mats of mycelium from the germinated spore it has been observed that some of the hyphal tips are recurved in the form of croziers. They have, however, never been seen to develop further, and it is impossible to say whether this development has any relation to development of spores, which are never produced except inside the tissue of the host. In hundreds of germination tests which have been made during three years in a large number of media, no conidia have ever been observed on the promycelium or its branches or anywhere else throughout the development of the organism. Sometimes the short lateral branches appear like conidia, but continued observation soon convinces one that they are merely vegetative branches which will elongate apically like other branches unless the supply of nutriment is exhausted.

Comparison with the Germination Process in Other Species of Urocystis.

Let us now compare this process with the process of germination which other investigators have described for other species of Urocystis.

Urocystis occulta Wallr., causing the flag smut of rye, was apparently the first species of this genus which was studied with respect to germination of spores, that process having been first observed and described by Kühn in 1858. It was later studied by Wolff (19), Brefeld (4), McAlpine (11) and others. According to Brefeld a promycelial tube of varying length is first produced, and at its apex it branches verticillately into a whorl of four to six branches. These branches increase in length by apical growth, and they, as well as the promycelial tube, become progressively septate, while the protoplasmic content of the older cells constantly disappears and the only living cells are those at, and just back of, the growing tips. The verticillate branches never produce conidia, but form mycelium by continued growth. McAlpine considers the verticillate branches themselves as conidia, but does not state that he ever found them detached. This resembles the process in *U. cepulae* in (1) the production of the whorl of branches, (2) the complete absence of sporidia and (3) the progressive emptying of the cells. The main point of difference is in the elongated, ultimately septate, promycelium in *U. occulta* which replaces the globose vesicle of *U. cepulae.*

In *U. Tritici* Koern. the process is almost identical with that of *U. occulta* according to McAlpine (11), but the promycelium is at times unicellular, a condition which suggests that of *U. cepulae.*

The germination process in *U. Anemones* (Pers.) Wint. has been studied by Fischer von Waldheim (7), Plowright (14) and Brefeld (4). As described and figured by Brefeld it is almost identical with the process which the writer observed in *U. cepulae* except that the promycelium is not so large. The whorl of 2 to 4 branches arises very close to the surface of the spore on a very much reduced promycelium, and they remain permanently sterile.

In *U. Filipendulae* Tul. (Brefeld (4)) the whole process is identical with that of *U. Anemones.*

Germination of the spores of *U. Violae* Sow. has been studied by Prillieux, Dangeard, Brefeld (4) and others, being a favorite subject for study because of the ease with which germination can be brought about in water. Each fertile cell of the spore ball produces an elongated promycelium which becomes septate just as in *U. occulta.* A whorl of three to eight diverging branches is produced at the apex. Each verticillate branch grows out at the distal end into a slender sterigma on which is borne a long cylindrical conidium. In nutrient solution these primary conidia may produce secondary or tertiary conidia. The process in this species differs from that of *U. cepulae* (1) in the length of the promycelium, and more especially (2) in the development of conidia.

In general, then, we may conclude that *U. cepulae* differs in its germination from the other species of Urocystis (except *U. Violae*) only in theshape of the promycelium which is here reduced to a nonseptate hemispherical vesicle. All other details of development appear to be identical.

Comparison with the Process as described by Thaxter.

As described and figured by Thaxter the spores germinate by a single long irregularly branched tube on the tips and lateral branches of which are borne small ellipsoidal to long ovoidal conidia. He does not mention a globose promycelium or whorl of branches such as the writer has always observed. The marked differences in the process as observed by the writer and as described by Thaxter are difficult to explain, unless they are due to contamination in the cultures used by the latter. He states that he was unable to obtain the material pure, and that "all the cultures swarmed with bacteria." The presence of these same bacteria might produce a difference in the development of the germination process. The writer in attempting to secure germination by Thaxter's method also failed to keep the spores free from bacteria and therefore changed to a different method.

III. Saprophytism.

The early botanists and mycologists believed that smut fungi were obligate parasites, *i.e.*, they developed only when in parasitic relation with host plants from the living cells of which they must take their nourishment. We now know, however, that at least most smut fungi have in their life cycle a saprophytic period during which they may develop extensively and propagate for a long time, deriving nourishment only from dead organic material in the soil or other substrata. Also most of them may be propagated indefinitely in artificial culture media of various compositions. Our knowledge of this stage began with the extensive investigations of Brefeld (3), and has been increased later by numerous smaller contributions from a large number of workers. *Urocystis cepulae* is no exception to the rule, and is very readily isolated and grown in a large number of culture media and on soil. It is probably able to exist and grow in the soil for years in entire absence of onions.

Isolation.

Two methods of isolation have been used by the writer. By the first method a germinating spore on an agar plate is located under the microscope by a ring of India ink, care being taken that this spore is far enough removed from all others to prevent confusion. When the mycelium from the germinating spore has increased to such an extent that it is visible to the naked eye as a tiny white speck it is transferred to an agar slant where it gradually spreads to the agar of the tube and can be grown for a long period. This method was used especially in the original isolations when it was necessary to know for certain that the resulting fungus originated from a single spore of *Urocystis cepulae.* In later work a more rapid method was used. A part of a cotyledon or young leaf containing a lesion which had not yet broken open was washed for a few minutes in mercuric chloride 1 to 1,000 and then in sterile water. The lesion was then cut into as many pieces as desirable and the pieces transferred to agar slants. One hundred per cent of pure cultures could be obtained in this way. Lesions of any age could be used, but the youngest were found to be most satisfactory.

Cultural Characters.

The range of media on which the fungus will develop is almost unlimited. Those which the writer has used are listed below along with a brief statement of the peculiarities exhibited by the organism on that particular medium.

Potato Agar.

The ordinary potato agar containing a boiled decoction from a large potato and 17 grams of agar to a liter of water. No sugar was added and the acidity was not determined. Growth very slow, reaching a diameter of 1 cm. in about ten days; very dense and compact like fine felt, snow white, dry, flat, but with considerable aerial mycelium; margin very definite and even. After about ten days the mycelium shows more and more of a tendency to grow beneath the surface of the agar, and the edge has the appearance of gradually fading away into the surrounding agar. Growth may progress for several weeks, but is gradually checked by the drying out of the agar. Some of the cultures show indistinct zonation. With age the surface of the felt may become rugose.

Oat Agar.

Growth more luxuriant than on potato agar, showing denser zones of white mycelium. No change of color in mycelium or in the medium. Growth not sufficiently different from that on potato agar to have any diagnostic value.

Nutrient Beef Broth Agar.

The standard agar of bacteriological work. Growth scanty, much less than on potato agar, slimy, and taking on the color of the medium; never dry, very little aerial mycelium. A very poor medium for growing the organism.

Czapek's Agar. [1]

This was found to be a very favorable medium, the growth being more rapid and with a greater abundance of white, cottony aerial mycelium than on potato agar. After about two weeks the agar below the growth, especially in the upper part of the tube, turns maize yellow, [2] due to the suffusion of a pigment. After about four weeks the color becomes more intense — aniline yellow or citrine yellow. With age this darkens to orange citrine or to various shades of olive. Also the mycelium as seen from above loses its white color after three or four weeks, showing various shades of greenish yellow — citrine drab, olive lake, etc. These color changes on Czapek's agar offer one good diagnostic character.

Onion Decoction.

Prepared by boiling a sliced onion in a liter of distilled water and sterilizing the filtered product for one hour at 15 pounds' steam pressure. Growth very slow, resulting in development of little compact balls of mycelium; brown when in the bottom of the tubes or white when on the surface of the liquid. Growth continues for months very slowly, but the little balls of mycelium do not attain a diameter of over 1 cm.

Onion Agar.

Prepared exactly like potato agar, but the onion decoction as described above is used instead of potato juice. This was found to be not only the best medium for culturing Urocystis, but also very much better than potato agar for growing many other fungi which the writer had occasion to try on it. It is very easily prepared, has a minimum of sediment even when not filtered, and altogether forms a very superior general purpose agar. Its only objectionable qualities are the obnoxious odor in the laboratory during preparation, and the fact that the growth of certain fungi is too luxuriant for some purposes. The growth starts with a dense white felt much like that on potato agar, but more rank. After about a week wrinkles begin to appear near the center, and these spread and become sharper and the irregular ridges more elevated with age, also at the same time the crests of the ridges become hygrophanous and gray. This appearance spreads until it involves

[1] For method of preparation see Soil Science, 2:113.

[2] All colors according to Ridgway's Color Standards.

the entire center or wrinkled part of the growth. The convoluted gray growth on onion agar is perhaps the best diagnostic cultural character of the species. It has been very constant in the many series of cultures which the writer has made with this agar. After a few weeks the color in reverse becomes darker, reaching cinnamon brown in about five weeks.

Sugar Potato Agar.

Prepared as potato agar with the addition of 3 per cent of saccharose. Growth is coarser in texture, more luxuriant and spreads more rapidly than on potato agar. The aerial mycelium is not snow white, but early assumes a cream color changing to cartridge buff after a few weeks.

Effect of Concentration of Sugar on Growth of the Mycelium in Culture. — In the series of cultures on different media it was observed that the best growth occurred on media containing considerable sugar, viz., Czapek's, sugar potato and onion agar. This led the writer to suspect that sugar is the essential element of nutrition both in culture media and on the host itself, since the onion contains a high percentage of saccharose. In order to determine the effect of sugar on the development of the organism, Czapek's synthetic agar was prepared first without any sugar and next with .5, 1, 2, 3, 5, 7 and 10 per cent of cane sugar. Five tubes of each were inoculated at the same time and accurate notes taken each day. No growth whatever occurred where no sugar was included. At the end of three weeks there was very little difference in the diameter of the growths on all the other concentrations, but those on the higher concentrates were a little more dense. The most apparent difference was in the color which was imparted to the agar. In the .5 per cent the culture was pure white in reverse, while in the 10 per cent it was bright yellow. The other concentrates formed a perfectly graded series between the two. The only other difference noticed was a wrinkling of the surface of the growth in some of the higher concentrates, and its entire absence from the cultures of low sugar content. Certain conclusions seem warranted from this experiment: (1) agar and inorganic salts alone do not furnish food for growth; (2) the yellow color in the agar is due to some reaction with the sugar; (3) the amount of growth (at least for three weeks) does not depend on the amount of sugar present. Any one of the concentrates apparently contained more than the maximum amount which the organism could utilize.

Substitution of Starch for Sugar. — In order to see whether the fungus can utilize starch as a source of carbon, agar tubes were prepared identical with Czapek's except for the substitution of soluble starch for saccharose. A scanty growth occurred, but even after four weeks it had not attained a diameter of 1 cm. and was very thin. Apparently, then, Urocystis can utilize starch, but it is a very poor source of carbon.

Soil Decoction Agar.

Prepared by adding 2 per cent of agar to the soil decoction described above. Growth was much less vigorous than on potato agar, and thin, but, on the other hand, spread almost as rapidly over the surface for the first few weeks. There can be no question whatever but that soluble elements in the soil furnish sufficient food for the development of the mycelium.

Dung Decoction Agar.

Prepared by adding 2 per cent agar to the dung decoction previously mentioned. Growth much thicker than on the soil decoction agar, but not as heavy as on Czapek's, sugar potato, etc. Dense white aerial mycelium. The conclusion seems warranted that horse manure furnishes all the elements necessary for the growth of the fungus, and is more favorable medium than a good soil. Apparently a heavily manured soil would be more favorable for the propagation of smut than one which was not manured.

Tolerance of Acid. — Four series of cultures were made on onion agar, — the first series without lactic acid; second, with 1 drop of lactic acid per tube; third, with 2 drops per tube; fourth, with 3 drops. All were inoculated at the same time. Growth was rank and normal in the series in which no lactic acid was added; no growth whatever in the series in which 3 drops were added; a very slight growth where 2 drops were added; growth much retarded in the 1-drop series. This series was begun with the purpose of finding a method of excluding bacteria from cultures of the smut fungus, but the latter was apparently checked by acid just as much as the bacteria.

Effect of Freezing the Cultures.

Cultures on potato agar and on onion agar were kept out of doors for two months during the most severe winter weather of 1919–20. Transfers were then made to fresh agar tubes, and the mycelium grew luxuriantly and rapidly on the surface of the slants. In fact, the growth at first seemed to be even better than when transfers were made from cultures which had not been frozen. Accurate measurements on a second series showed a slight difference in favor of the transfers from frozen mycelium during the first few days, but it was not permanent. We may conclude, then, that freezing not only does not injure the mycelium, but possibly stimulates it to even better growth.

Microscopic Characters of the Mycelium in Culture.

The characters of the mycelium differ somewhat with the age of the culture. Microscopic examination of a culture a week old shows slender hyaline hyphæ of rather uniform diameter, about 2μ, with rather indistinct septa and homogeneous contents. Branches arise almost exclusively from the upper ends of the cells and diverge at a wide angle. The characters have not changed from the condition previously described under germination of the spores. Not all of the cells of the mycelium appear to be alive; some of them are empty and apparently dead; others are full of homogeneous protoplasm with no vacuoles. Under the oil immersion lens one notices certain very refractive granules scattered throughout the dense protoplasm (Fig. 2, A). The cells are easily broken apart, and when a mount is made the hyphæ appear in segments as represented in the figure. At this early stage they show no constrictions at the septa. No conidia can be found. Clamp connections have not been observed.

If, however, cultures several weeks old are examined microscopically it will be observed that certain changes have taken place. The aerial mycelium may remain about the same as described, except that the cells appear vacuolated, but there will now be found a different kind of mycelium beneath the agar surface. These hyphæ are stouter, averaging 3.2μ in diam-

FIG. 2. — Details of hyphæ in culture. Detached hyphal cells at C and further development of same at D.

eter, the cells are much shorter, the septa very distinct, and the hyphæ decidedly constricted at the septa, so much so that the hyphæ appear almost like strings of separate cells. A large proportion of the cells become shaped like dumb bells. When disturbed, as in mounting, the cells of the thread break apart very readily so that when one makes a mount of an old luxuriant culture, such as on onion agar, he hardly finds mycelium at all, but only these irregular separate units. Most of them are branched at the tip. A strand of this mycelium is represented in Fig. 2, B, with a young ordinary hypha for comparison. The appearance of the separate cells from an onion agar culture as seen floating about in the microscopic preparation is represented in Fig. 2, C.

Fate and Function of the Detached Hyphal Cells.

Since these large detached cells appear so early in the development of a culture and in such large numbers, it does not seem probable that they represent merely a stage in the degeneration or breaking down of the mycelium. Apparently they have some rôle in the life history of the organism. In order to determine whether they are capable of further development, a culture was thoroughly shaken in water and the detached cells floated out on sterile agar plates as described previously for germination of the spores. Within twenty-four hours slender tubes of about half the diameter of the original cells could be observed growing out from them. These tubes originate from one or from both ends of the cell, quickly become septate and branched, and within three days each is the center of a white mycelium which can be seen with the naked eye. The centrifugal emptying of the cells, the branching, and all other characters are the same as those of the growths from the chlamydospores. Practically 100 per cent germinated. No conidia could be found on them at any stage. The development of these cells is represented by Fig. 2, D.

Taken in connection with the fact that no true conidia have appeared in any of the cultures, the conclusion seems warranted that these cells detached by division of the vegetative hyphæ are analogous to and serve the same purpose as the sporidia (conidia) of other smut fungi in propagation and dissemination. In fact, almost any cell of the mycelium which retains its protoplasm is a potential spore, and may serve all the functions of the same. Since the cells are so easily detached and germinate so quickly and universally, their importance in the distribution of the disease can hardly be overestimated.

Life in the Soil.

There are at least two ways in which the organism may pass from the host into the soil; (1) when the spores are mature and the sorus is exposed by rupture of the enclosing host tissue, the spores fall out or are blown or shaken out by various agencies and fall to the ground; (2) as previously described, mycelium from any buried lesion may grow from the disintegrating tissues directly into the surrounding soil. It has also been indicated in cultures on soil extract media that the soil contains all the elements necessary to induce germination of the spores and to nourish the mycelium into further growth. In order to study further this period of development of the organism, pure cultures on soil were made by inoculating Ehrlenmeyer flasks of sterilized soil, some by placing a small portion of diseased cotyledon on the center of the surface of the soil, others by placing bits of mycelium from agar tubes in the same position. Within a few days the mycelium could be seen plainly with the naked eye passing from both into the soil and spreading over its surface. After four weeks it was isolated from all points of the soil surface. After more than a year it could still be isolated in pure culture. Microscopic examination of mycelium from the soil showed the same characters that are previously described for cultures and the same detached cells.

Summary of the Saprophytic Stage in the Natural Life History.

From all that has preceded concerning this stage we may draw some conclusions.

1. The fungus lives naturally in the soil, especially where there is an abundance of organic material.

2. It derives sufficient nutrient materials from the soil to grow and spread extensively during this stage.

3. It enters the soil either as spores or as mycelium from the buried parts of diseased onions.

4. No typical conidia (sporidia) are produced but it can be widely disseminated by the detached mycelial cells which may be carried about by water, wind, rain, tools, animals, workmen, etc.

5. It probably lives in the soil in this state for years without the presence of onions.

6. As will be shown later, infection may take place directly from this mycelium, and the presence of spores is not necessary.

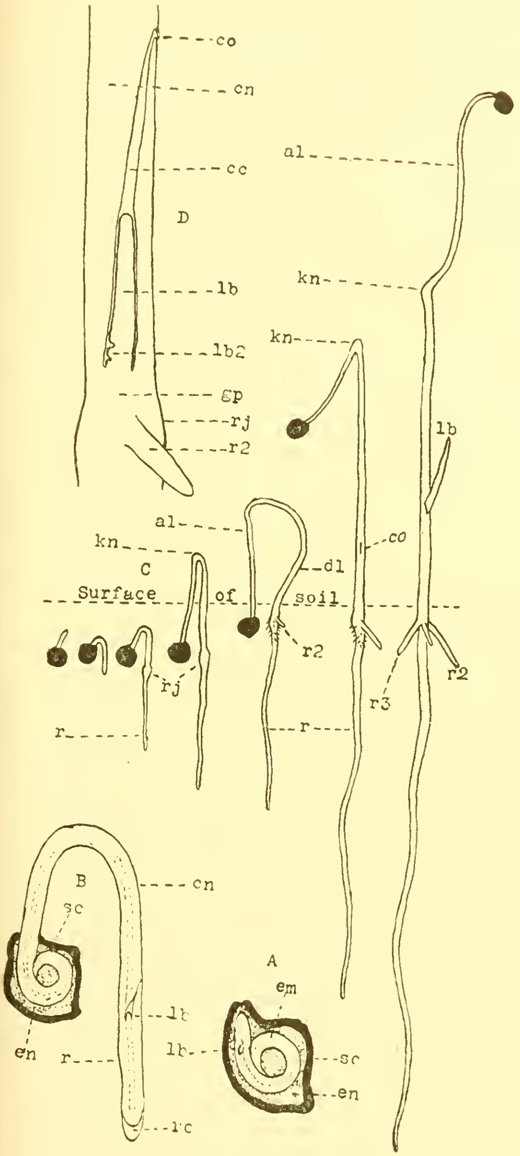
7. The number of years which must elapse before onions can be grown safely on an infested piece of land is not necessarily decided by the longevity of the chlamydospores, but in all probability by the length of time during which the mycelium can continue to live and develop saprophytically without having to pass again through a parasitic stage.

IV. Infection.

Very little has been published concerning infection except the bare fact that it occurs at an early period in the growth of the plant. Concerning the method and point of entrance, character of inoculum, etc., nothing has been previously ascertained.

Development of the Onion Seedling.

In order to understand the description of infection given below it is necessary that the reader should know something of the stages through which an onion seedling passes during the process of germination. The resting seed consists of a hard, black outer seed coat, a nutritive endosperm, and an embryo. The embryo is coiled like a snail within the endosperm (Fig. 3, A). The larger part of the coil represents the cotyledon; only a short portion of the free end is the radicle. In the lower part of the cotyledon, just above where it joins the radicle, there is, even at this early stage, a small cavity. A minute bud, *lb*, arises from the base of and projects into the cavity. This bud is the primordium of the first leaf, and the cavity in this and later stages is called the cotyledonary cavity, *cc*. Several layers of elongated cells throughout the length of the center of the embryo indicate the position which the fibrovascular bundle of the seedling will occupy. Germination begins with rapid elongation of the embryo, the radicle and lower part of the cotyledon being thus pushed through the micropyle, a small opening in the seed coat. This elongation is effected both by longitudinal stretching of the cells of the embryo and by cell division. Food and water for this activity are absorbed by the upper end of the cotyledon which remains attached in the endosperm. On the third day after planting, the projecting radicle is about 3 to 4 mm. long. The root usually points upward as it emerges, but geotropism soon causes it to turn downward and the cotyledon describes a sharp curve as indicated in Fig. 3, B and C. It will be noticed that the tip of the leaf bud now



A. Section through a resting seed.

B. Longisection of a seedling four days after planting.

C. Successive stages in the development from the third day to the twenty-fifth day.

D. Diagrammatic longisection through the growing zone at the end of two weeks. Symbols for parts are the same in all:

sc, seed coat.
en, endosperm.
em, embryo.
lb, leaf bud or primordium of first leaf.
rc, root cap.
r, radicle or first root.
cn, cotyledon.
rj, root joint.
kn, knee.
al, ascending leg.
dl, descending leg.
co, exterior opening of cotyledonary cavity.
r2 and *r3*, first and second secondary roots.
cc, cotyledonary cavity.
gp, growing zone, region of origin of all leaves and roots.
lb2, primordium of second leaf.

Fig. 3. — Development of an onion seedling.

points upward. At this early date the point of division between radicle and cotyledon is indicated by a slight swelling, the root joint, *rj*. As all the parts continue to elongate rapidly the curve in the cotyledon becomes a sharp knee, *kn*, the part between the knee and seed is the ascending leg, *al*, while that between the knee and the root joint is the descending leg, *dl*. The primary root grows down very rapidly and is soon several times as long as the cotyledon. From about the fifth day it will be noted that the descending leg elongates more rapidly than the ascending leg. The first part to appear above ground (seventh to tenth day) is the tip of the knee, and each part becomes green as soon as it has reached the light. The seed may still remain in the ground for a week or more after the knee has appeared, but since it is firmly attached, and since the descending leg continues to elongate more rapidly than the ascending leg, the seed is finally carried into the air (Fig. 3, C). The knee then has a tendency to straighten out, but its position is indicated as long as the cotyledon lives by a sharp kink. On about the ninth or tenth day the first secondary root, *r2*, may be seen pushing out from the swollen root joint, and this is followed later by others in rapid succession, *r3*. Meanwhile the first leaf bud has been elongating rapidly. The cotyledonary cavity elongates also in proportion (Fig. 3, D). It should not be understood that this cavity is absolutely included, without any opening to the outside; on the contrary, its upper narrowed apex communicates with the outside air through a small longitudinal slit in the side of the cotyledon (CO in Fig. 3, C and D). As the leaf bud pushes its way upward the sides of the cavity are distended, and finally from about the seventeenth to twenty-fifth day the tip passes through the slit and appears on the outside as the first leaf (*lb* in Fig. 3, C). But before this time the primordium of the second leaf, *lb2*, has appeared in a depression at the base of the first, and successive leaves follow rapidly, each starting from the base of the next preceding at a very early stage. The successive secondary roots also start from the same region. This very active meristematic region, the growing point, *gp*, is very restricted, and remains stationary in the onion until after the bulb is formed. The limited size and stationary position of the growing point from which all new organs, roots or leaves, originate are characters of prime importance in the spread of the smut fungus within the host plant.

Period of Susceptibility.

It is a well-known fact that onions are susceptible only in the seedling stage, and are immune after a certain stage of maturity is reached. But we have no exact knowledge of the duration of this period of susceptibility, the exact stage or time at which infection first occurs, or the stage or time at which it ceases. The establishment of two points is thus necessary: (1) the first day on which infection takes place, and (2) the last day during which the plant can be infected. The latter of these two points was established by the following experiment. Seed was planted in a flat of sterilized soil. Beginning with the third day, when the radicle on the most advanced was less than $\frac{1}{2}$ cm. long, and had not even started in many of them, 50 plants were transferred each day to soil which was badly infested and which could be depended on to produce almost 100 per cent of infection. Notes were made on the stage of development of the seedlings each day, and a careful record was kept of all the plants which became smutted. After six weeks, when the plants were mostly in the fourth leaf (after which infection never starts), all of them were pulled, and the following table compiled to show the complete results of the experiment: —

Days between Planting and Transplanting.	Percentage of Infection.
3	100
4	100
5	95
6	100
7	100
8	98
10	87
11	87
12	70
13	59
14	15
17	6
18	–
19	–
Check (left in original sterile sand)	–

The following conclusion may be drawn from this experiment: Under greenhouse conditions the greater part of the infection occurs within two weeks after planting, and the plants are no longer susceptible after the seventeenth day. Since it seems probable that the period of susceptibility is not limited by the number of days during which the seeds have been in the soil, but by the length of time required for the seedling to pass through certain stages of development, we may express this first conclusion by stating that susceptibility begins to diminish from the time that the knees emerge from the ground, and that little if any infection occurs after the first leaf has emerged from the side of the cotyledon. In a large number of experiments in the greenhouse at all times of the year it has been found that the knees begin to appear above ground in seven to twelve days. In one experiment, where the house was very cool, it required over two weeks, and in this case the percentage of infection was 100, and the individual plants were more thoroughly smutted than in any other experiment tried. Since, then, the period of susceptibility might be increased by the length of time required for the seedlings to reach a certain stage, it is well to inquire how the rate of growth in the greenhouse compares with that in the field. During the spring of 1920, when the spring was late and cold, onions in the field did not come up for over two weeks in most cases, but growers have frequently told the writer that they have had fields which came up within eight days. Apparently weather and soil conditions may materially affect the length of this period. Depth of planting might also influence slightly the length of the period and also the chances of infection. The experiment reported above, however, gives us no information as to the date when infection begins, but only indicates that it ends with about the seventeenth day.

In order to determine the stage at which the earliest infection starts, — and at the same time to work out other points in the early life history, — another bed of onions was started in the greenhouse with soil known to give 100 per cent of smut infection. Beginning with the third day, a certain number of plants was dug up each day, fixed in Flemming's weaker solution, run up into paraffin, sectioned, mounted serially and stained with triple stain. No mycelium was found in the tissues of those which were fixed on the third and fourth days. The first infection was found in a plant which was dug up on the fifth day after planting, and was apparently a very young infection because it had at no point penetrated more than to the fifth layer of cells below the epidermis, and at its furthest point was not more than 150μ from the point of infection. Fifteen other plants dug at the same time were carefully searched under high power through every section of 92 slides, but no other trace of mycelium was found. It is probable, therefore, that only rarely, if ever, has the mycelium entered the tissues of the plant on the fifth day after planting (second day after germination has started). Since cultural experiments with the smut fungus have shown it to be of very slow growth, at least in the saprophytic condition, it seems hardly possible that it could have succeeded in entering the tissues before the second day after germination of the seed starts.

It may be concluded from everything which has been learned up to the present in regard to the period of susceptibility that *infection may take place at any time between about the second day after the seed starts to germinate until the seedling is in the first leaf* (a period of about twelve days in the greenhouse).

Point of Infection.

In the study of the plants fixed and stained as mentioned above, many very young infections were found where it was possible to determine the point of entrance for the mycelium. Infections were found at the knee above, at the root joint below, and at various points between, also at least one through the interior wall of the cotyledonary cavity. The conclusion is, therefore, that all points of the epidermis at least between the root joint and the knee are susceptible to penetration by the smut tubes. Infection was never found taking place in the roots proper or between the seed and knee. From observation of mature sori, however, it seems probable that infection sometimes occurs above the knee. Mycelium in various quantities has been found in the cotyledonary cavity of many plants, even in the youngest stages, and by tracing it to the opening of this cavity it can be seen that it comes in from the outside through the natural opening, but in most cases it has been impossible to trace a direct connection between this mycelium and any hyphæ inside the tissues between the cells. This mycelium has the size and all the other distinctive characters of smut mycelium, but it is not possible to prove that it is such. It was thought at first that this was the usual infection court, but after it was demonstrated beyond any question that in a large number of cases young infections could have no connection whatever with this cavity, the conclusion was reached that only a small part of the infection could be accounted for in this way. It is still doubtful whether the mycelium which was found in the cavity was always that of Urocystis, or whether it may have been that of another soil fungus.

It is probable that *all infection takes place through the cotyledon*. A case was never noted where the leaf became smutted while the cotyledon remained healthy. More careful experiments on this point, however, might show that the leaf does sometimes become infected first. It is probable that all infection takes place beneath the surface of the ground.

Character of the Inoculum.

In all literature on onion smut it has been assumed that the spores of the organism must be present in close proximity to the seedling in order that infection may occur. The possibility that the mycelium might be present and growing saprophytically and indefinitely in the soil, and might infect without the immediate presence of spores, has been left out of consideration. In order to determine the ability of saprophytic mycelium to produce infection, onion seeds were germinated beneath the surface of agar cultures in test tubes in such a way that the developing seedling as it elongated must pass through the mat of mycelium. Over 50 per cent of the seedlings became infected, although no smut spores could have been present. In the stained sections which were studied, in a few cases mycelium was found outside the walls of the epidermal cells where infection has occurred. Only in one case were spores found in these sections, and at that time there was no infection beneath them. It is probable, however, that spores would usually be removed by the washing process, and this could hardly be adduced as conclusive evidence against the necessity of spores for infection. It is probable that *either spores or saprophytic mycelium in the soil can serve as the inoculum.*

Method of Entrance.

The infecting hypha enters the epidermal cell by boring directly through the outer wall. Since in the younger infections the stomates are not yet open, and mechanical wounds have not been found, there is no other route by which it could make its way into the interior tissues of the plant. A stage of infection has not yet been found so young that the tube has just entered the epidermal cell and has not progressed further.

Passage through the Epidermal Cells.

In the youngest infections observed, the mycelium had already grown through the epidermal cells, and its tips could be found in the intercellular spaces at a depth of two or more layers below. In some cases a piece of the infecting hypha still remained on the exterior of the cuticle, but was always devoid of contents and consisted only of somewhat crumpled walls

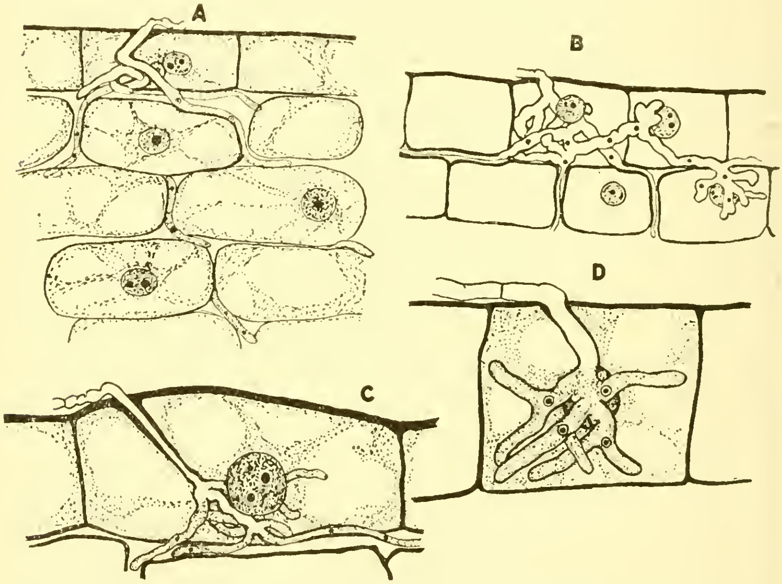


FIG. 4. — Infection through the epidermal cells; A, B, C from outside the cotyledon, D from the cotyledonary cavity.

(Fig. 4). A broad clear canal passes inward from the outer wall usually directed toward the cell nucleus. The wall of the canal appears to be continuous with the cell wall as if merely an inward extension of the same. Commonly it is much thicker at the point of entrance, and resembles a slender funnel or trumpet in shape. It was not found possible to determine whether part of the wall of the canal is an inward growing sheath of the same substance as the cell wall, or whether it is merely a thickened wall of the hypha. In all the cases observed, the canal was empty at the point of entrance. The host nucleus appears to exert an attractive influence. When the tube has reached the depth of the nucleus, it branches to form a tangle of stout, swollen, gnarled, hyphæ which may be confined to the region immediately about the nucleus, or may reach to all parts of the lumen of the host cell (Fig. 4). They may be entirely devoid of contents or — depending on the stage at which one finds them — may contain protoplasm and bright red nuclei scattered singly or in pairs. The hyphal tangle may be confined to the lower (inner) part of the cell, and is always more dense there (Fig. 4, C). Its windings are difficult to follow. These intracellular windings stain red with the triple stain. There is a marked contrast between the large, swollen winding intracellular hyphæ and the trim, slender, straight intercellular hyphæ between the cells below, which stain violet and are of only about one-half the diameter of the former. Usually the tangle is confined to one epidermal cell, but sometimes the adjacent cells may be invaded (Fig. 4, B). The attacked epidermal cells do not collapse, and, in fact, appear practically normal. Hyphæ pass down from the tangle through the inner wall of the epidermis into the intercellular spaces immediately beneath.

Multiple Infection.

The same plant may suffer from a number of infections. In one plant fixed eight days after planting, the mycelium was found passing in through the epidermis at six points on a piece of the cotyledon less than a centimeter in length. In young stages it is not difficult to trace each mycelium to its limits between the cells, and in this case no one of the six had come into contact with another. It is not unusual to find seedlings which show five or six sori on the same cotyledon. Microscopic examination indicates that these are not the results of a single infection, but that for each sorus there is at least one infection thread which penetrated the epidermis from the outside. This statement, however, does not apply to the sori which appear later on the true leaves.

V. Incubation Period.

The incubation period is the time which elapses between infection and the first externally visible symptom of disease. Since the first external symptoms appear at approximately the same time that the spores are forming, we may say that the incubation period is that segment of the life cycle between infection and sporogenesis. In the greenhouse the first symptom, a slight curving and thickening of the cotyledon, has been observed here on the tenth day. Since, as previously stated, infection may take place as early as the fifth day, we may consider that this period occupies a space of about five days under favorable conditions in the greenhouse. It may be longer outside, but, at most, is a comparatively short period. During this period the parasite grows rapidly, spreads inside the host and prepares to form spores.

Young Hyphæ in the Intercellular Spaces.

After passing through the epidermis the hyphæ are intercellular during the remainder of their development. Just below the inner epidermal wall they spread in all directions. They are long, slender, and, as they pass along the longitudinal walls, appear very straight. They appear to progress somewhat more rapidly up and down the cotyledon than in a radial direction inward. In the young stages they do not occur in strands or bunches between the cells, but one finds them running singly (Figs. 4, A and 5, D). They do not appear to be going toward any definite point, but are spreading more or less in all directions. They are undoubtedly septate, but the septa in the very young hyphæ are difficult to distinguish. The protoplasm passes to the growing tips, and leaves empty the cells behind it. These tip cells stain deep violet with the triple stain, while those cells behind them take less and less stain until only the thin line of the walls can be seen. The nuclei stain bright red and are very prominent, especially back of the deep violet tip cells. These nuclei may occur singly or in pairs distributed along the hyphæ. At this stage it is not always possible to tell whether the two nuclei of a pair are in the same or different cells, but by a comparison with what is found in hyphæ somewhat older, it is probable that here also the cells may be either uninucleate or binucleate. The contents of the hyphal cells appear homogeneous, and at this stage there are no vacuoles or oil drops. The hyphæ seem to be mostly tightly pressed against the walls of the cells, but at places can be seen passing from the wall of one cell to that of another across the open spaces. The cells are long and the branching not close as in the later stages. The branches always arise monopodially from just below the septum, as previously described.

Haustoria.

These absorbing organs are not numerous, but are not uncommon. In some infections none could be found, while in others they are fairly common. They are of various sizes and of very irregular shape (Fig. 5, A–E). They are not much different from the haustoria of other smuts as described by various writers. They are always very much branched, but the branches may be reduced to mere knobs or short stubs which are frequently bifid at the apices (Fig. 5, A). In the larger haustoria, however, the branches are longer and more lax, and may go to all parts of the cell (Fig. 5, B and C). The branches of these larger haustoria are usually — but not always — imbedded in the protoplasm about the nucleus. In some cases they seem to be tightly gripping the nucleus, and the latter appears indented by the pressure. Their shape and size can be best understood by reference to the figures. In many of them an appressorium-like expansion of the hypha can be seen flattened against the outside of the cell wall, and from the lower side of this expansion a narrow neck passes through the wall (Fig. 5, A, E). It is not certain, however, that this appressorium is always present. In the larger haustoria, red nuclei can be distinguished in varying numbers, but in smaller ones, and, in fact, in many of the larger ones, no nuclei can be seen. In some, the position of the nucleus in the stalk of the haustorium is evident (Fig. 5, C) but apparently there is no uniformity either in the position or number of nuclei. The haustoria usually stain yellowish brown with the orange G of the triple stain.

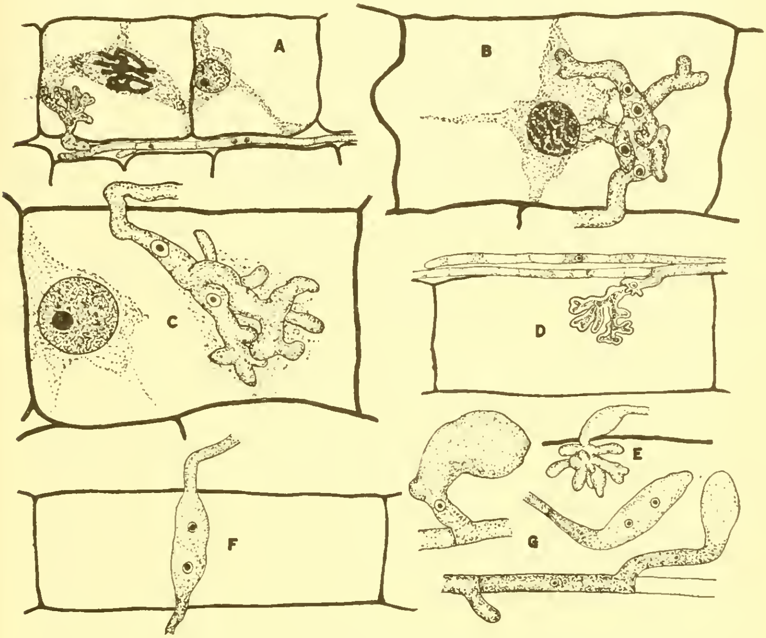


Fig. 5. — Haustoria (A–E) and absorptive hyphal expansions (F, G).

Absorptive Hyphal Expansions.

Frequently during the incubation period one finds the tips, especially of short lateral branches, flattened out like spatulas against the cells of the host. In some sections, just before sporogenesis, these structures may be found in great numbers. Usually they are terminal (Fig. 5, G), but not infrequently they may be found intercalary within the ordinary course of a hypha which, beyond the expansion, continues in its normal size and shape (Fig. 5, F). They resemble the appressoria previously mentioned as the bases from which the haustoria arise, but their number is out of all proportion to the number of haustoria which one finds in the same sections. No description of these organs has been given elsewhere, and their function or meaning is not clear. One can only conjecture that their purpose is to present a broad absorbing surface for securing more nourishment from the host cells. It seems doubtful whether haustoria are really necessary in this connection, because many infections have been studied under the microscope in which no haustoria could be found.

Progressive Infection of New Leaves.

It is a common belief, supported by statements in the literature of the disease, that when a seedling once becomes infected it never recovers. Such, however, is not the case. The writer has watched the development of many seedlings which had infected cotyledons, but which developed into healthy onions. On the other hand, he has not seen an onion, in which the *first leaf* was affected, which produced a healthy bulb. Usually each successive leaf will show smut sori, and they are not always in any apparent relation to the sori on older leaves. As previously stated, all infections come through the cotyledon, but the fate of the plant depends on the point in the cotyledon at which infection takes place. If it occurs only high up toward the knee, or above it, there is a pretty good chance that the host tissue will have become mature or dead and no longer suitable for spread of the mycelium before the latter has reached the growing zone, and the bulb will develop normally. But if infection occurs at or very near the root joint, the mycelium quickly penetrates tc the growing zone from which all future leaves arise. This meristematic tissue furnishes the ideal condition for continuous vegetation of the pathogene, and as each new leaf pushes out from this restricted stationary zone it contains filaments from which the new sori of the successive leaves develop. When the parasite is once established in this growing point, the host seems never to be able to shake off its grip, and is doomed. It is not quite so clear why the mycelium does not enter the tissues of the developing roots in the same way, but the writer has never been able to find it in these organs.

VI. Sporogenesis.

The approach of spore formation is first indicated by massing of the mycelium between the cells. Up to this time only long straight slender hyphæ are found spreading singly, or at most not more than two or three together, between the cells. The period during which the pathogene appears to be spreading as widely and rapidly as possible between the cells has just been described as the incubation stage. The distributive hyphæ now begin to branch profusely, and the branches are not straight and parallel to the main hyphæ, but become twisted and interwoven into dense tangles which push the cells apart and increase the area of intercellular spaces within which the spores are to be formed. The hyphæ now become highly vacuolated, and the protoplasm between the colorless vacuoles stains densely blue with the triple stain, while the old cells from which the protoplasm has passed take the orange stain. The beaded appearance of the alternating vacuoles and densely staining cytoplasm is the surest indication of approaching sporogenesis.

These spore nests or sori always occur between the cells of the mesophyll anywhere between the epidermis and the bundles, but have not been found inside the bundles. They are extended in the direction of the length of the leaf or cotyledon.

Observation of the exact course of events in the formation of a spore is rendered difficult by the denseness of the mass of developing spores, and by the fact that in the young stages all the developing parts stain so deeply on account of their very active protoplasm that the nuclei and septa can hardly be made out. In all cases which have been observed, the spore begins as a lateral or terminal branch which curves back on itself in the form of a crozier (Fig. 6, A–I). These hook-like croziers may be seen in enormous numbers in the mycelial tangle at the initiation of sporo-

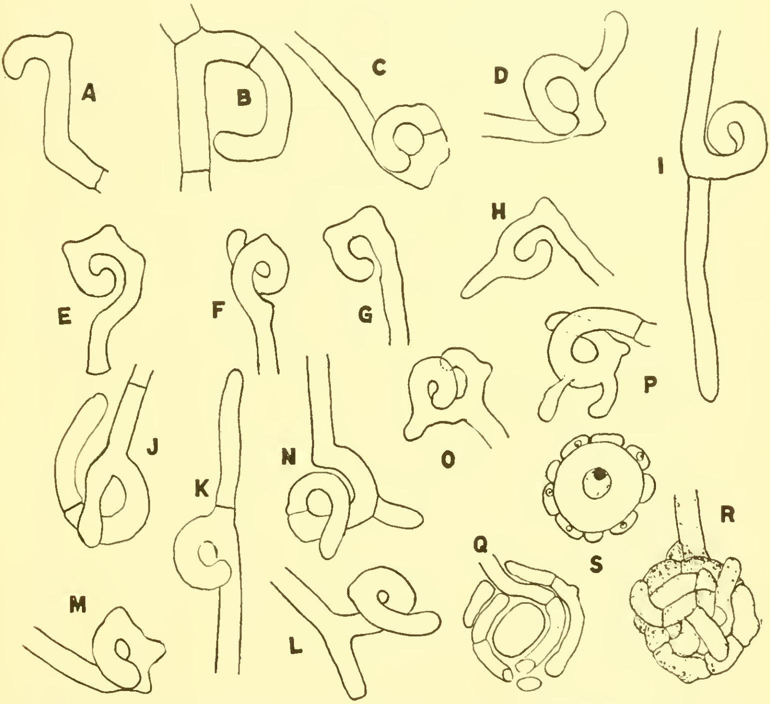


Fig. 6. — Stages of sporogenesis. A–P, development of the crozier and origin of the enveloping hyphæ; Q, section through young spore which is shown in surface view at R; S, section through mature spore.

genesis. Even after the spores at the center of a sorus are fully formed, one may still find various stages of development extending as far back as the crozier, as he passes from the center toward the periphery of the tangle. The croziers remind one of those from which the asci of the Ascomycetes are developed. They stain very deeply, and apparently the protoplasm from the other cells of the hyphæ passes into them. The various shapes which they may assume are best understood by consulting Fig. 6. By growth from the apex of the crozier a complete circle is soon formed and then a spiral if further terminal elongation occurs (Fig. 6, F, L, N, P). At about this time the crozier or spiral begins to appear angular and irregular (Fig. 6, M), due to protuberances which mark the origin of short lateral outgrowths which soon curve inward along the surface of the developing ball (Fig. 6, P). The whole structure becomes so complicated at this time that it is not always possible to make certain of the exact course of events. The surface view now shows a dense ball of interwoven hyphæ (Fig. 6, R). A cross section (Fig. 6, Q) shows that at the center there is a larger cell which represents what will later be the fertile cell of the spore. This cell appears to be the enlarged terminal cell of the crozier, though it is not certain that this is always its origin. Also it is not entirely certain that all the branches which form the outside of the tangled mass arise directly from the surface of the crozier. In some cases one gets the impression that other hyphæ may be involved, or that branches arise from below the crozier on the same hypha. The transformation from the stage represented in Fig. 6, Q, R, to the mature spore is very rapid. The central cell enlarges while the cells of the surrounding hyphæ become pressed tightly against and united with it. The union between the central cell and the cells of the enclosing hyphæ appears to be stronger than that between the cells of a single hypha of the latter; at any rate, the hyphæ now break up and their elements no longer appear as cells of individual hyphæ, but as scattered conical cells whose flattened bases are firmly attached to the surface of the central cell (Fig. 6, I). This involves a decided change in shape as well as orientation. Nothing has been seen in this process which could be called a gelatinization of cells, such as has been described so often as occurring during sporogenesis in the Ustilaginales.

Approximately at the center of the fertile cell of each fully developed spore there is a nucleus which stains very prominently at this stage of development (Fig. 6, S). In thousands of beautifully stained spores examined by the writer, more than a single nucleus has never been found. It is 3 to 4μ in diameter, with a prominent very red single nucleolus of about .6μ diameter, usually in contact with the nuclear membrane. The membrane is very plain, but the nuclear content, with the exception of the nucleolus, appears only as a few fine granules of cromatin aggregated about the nucleolus or around the inside of the membrane. In each accessory cell there is a single small nucleus of about the diameter of the nucleolus of the fertile cell. In *Urocystis Violae*, Dangeard reported that there were no nuclei in the accessory cells. With the staining methods used it was impossible to determine whether the nucleus of the mature spore results from the fusion of two nuclei. In *U. Anemones* (Pers.) Wint., Lutman found that the cells of the vegetative hyphæ are binucleate and remain so until after the formation of the spore ball, and that the large nucleus of the mature fertile cell results from fusion of the two nuclei. Such might well be the case here, because in the vegetative hyphæ, as previously mentioned, about half of the cells are binucleate, while in the mature spores all cells are uninucleate.

With the full development of the sorus, the host tissue above it dries out and may split open and permit the escape of the dry powdery mass of spores. In the larger leaves the opening of the sorus may first occur on the interior of the hollow leaves. Under moist conditions other fungi, such as Fusarium, may cause the tissue to decay more rapidly, and thus aid in the liberation of the spores.

The first outward indication of disease in a young seedling is a slight curvature of the cotyledon accompanied by some enlargement of the affected part. In the greenhouse I have found these symptoms as early as the tenth day after planting. Within another day or two, when an affected seedling is held so that the light will shine through it, the lesions may be located by the darker appearance. As soon as the spores are mature the dark sorus can be seen through the tissue without holding it up to the light. The length of time which elapses before it splits open and permits the escape of spores varies greatly with the weather, age of leaf, and other factors.

VII. Summary.

1. Spores as soon as mature germinate in the laboratory in onion decoction, sugar solutions, onion decoction agar, soil agar, manure decoction agar and various agars containing sugar.
2. They do not germinate in tap water, distilled water or soil water.
3. The presence of the onion or any substance from the onion is not necessary.
4. Freezing does not increase or hasten germination, but when spores are frozen in the ground they are not killed.
5. Free access to air increases the percentage of germination.
6. A period of rest in damp soil increases the percentage of germination, but is not necessary.
7. In the soil the spores do not all germinate at once, but become progressively prepared for germination. They do not wait until a host plant starts to grow near them.
8. Germination begins in three to six days after the spores are brought under favorable conditions.
9. A short hemispherical promycelium is first developed, and from this a whorl of branches grows out.
10. The branches grow as mycelium indefinitely without producing conidia (sporidia). The older cells become devoid of their protoplasm progressively.
11. The germination process is very similar to the same process in other species of Urocystis, being almost identical with that of *Urocystis Anemones*. Of the investigated species of this genus, only *U. Violae* produces sporidia.
12. *Urocystis cepulae* lives and grows as a saprophyte indefinitely in the soil, its growth being favored by manure.
13. It may be grown in pure culture on a wide range of culture media, and shows cultural peculiarities by which it may be distinguished from other fungi.

14. Sugar in the media greatly increases the growth. The same substance probably accounts for its rapid growth in the host.

15. Starch furnishes a very poor source of carbon.

16. Decoctions from soil or manure furnish all the essentials for growth.

17. A small amount of acid checks its growth.

18. Freezing does not kill the mycelium.

19. No sporidia (conidia) have been found by the writer in pure cultures or in soil.

20. The mycelium at an early stage breaks up into short plump cells which have all the functions of sporidia and are probably of great importance in dissemination.

21. The organism gets into the soil either by means of spores when the sorus is broken up, or as mycelium which grows from the lesions when in contact with moist soil.

22. Infection occurs during the time from the second day after the seed germinates until about the time that the first leaf appears on the side of the cotyledon, after which the plant is immune.

23. Infection occurs only through the cotyledon, and any part of its epidermis may serve as the point of infection.

24. The infecting hypha bores directly through the outer wall of the epidermal cell, forms a hyphal gnarl inside the cell, and then passes through the inner wall into the intercellular spaces where it grows during the rest of its development.

25. Many infections may occur on the same cotyledon.

26. The incubation period is less than a week.

27. Large complicated haustoria are formed within the host cells.

28. An infected plant recovers if the fungus fails to reach the growing zone; but if it once becomes established in this zone, the plant never recovers, and most if not all the leaves will contain lesions.

29. At the close of the incubation period the mycelium is in dense masses between the cells, and from this the spores develop in sori.

30. The spore begins as a recurved lateral or terminal branch, forming a crozier, circle or short spiral.

31. Branches arising from the circle (crozier) form a close covering about the terminal (fertile) cell.

32. By adhesion of the cells of the covering hyphæ and rapid expansion of the fertile cell the enclosing hyphæ are separated into the scattered elements which appear as the sterile cells of the mature spore.

33. The fertile cell contains a single, large nucleus, and each sterile cell a single small nucleus. Probably the large nucleus is a result of fusion.

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BULLETIN No. 205.

DEPARTMENT OF CHEMISTRY.

THE NUTRITIVE VALUE OF CATTLE FEEDS.

3. DRIED APPLE POMACE FOR FARM STOCK.

BY J. B. LINDSEY, C. L. BEALS AND J. G. ARCHIBALD.

Introduction.

Apple pomace is the residue after the extraction of the juice from apples. This has usually been done by many small cider mills located in the various country towns, but of late years the business of cider and vinegar manufacture has become more centralized in large plants employing the most modern machinery. The large establishments in Massachusetts are those of W. W. Cary & Son, Lyonsville; the E. F. Gerry Company, Lynnfield Centre; F. E. Jewett & Son, Lowell; New England Vinegar Works, Somerville; and the Sterling Cider Company, Sterling. After the extraction of the juice, the pomace has been thrown away or used more or less by farmers in the vicinity of the mills. One large concern reports that much of the pomace is taken by the farmers, well packed in silos, and fed during the winter. More recently, two manufacturers (Sterling Cider Company and W. W. Cary & Son) have dried the pomace, the latter company reducing its water content from 63.5 to less than 10 per cent. The value of this dried pomace for feeding purposes has been the subject of our study, and the results are presented in this bulletin. The material for the work was received from W. W. Cary & Son, whose plant we have visited and inspected on two occasions.

The number of cider apples produced in Massachusetts naturally varies much from year to year and no exact data on the subject are available. Munson of the Massachusetts Department of Agriculture states that the difference between the total crop of apples and the commercial crops for the last five years was as follows: —

	Bushels.				
	1916.	1917.	1918.	1919.	1920.
Total crop,	3,450,000	2,186,000	2,430,000	3,240,000	3,680,000
Commercial crop,	1,551,000	675,000	900,000	1,005,000	1,125,000
Difference,	1,899,000	1,511,000	1,530,000	2,235,000	2,555,000

This difference, according to Munson, represents the apples which were not sold in the larger markets but remained on the farm and were wasted or used for by-product purposes, including cider. W. W. Cary & Son use an average of about 60,000 bushels a year; the New England Vinegar Works used 90,000 bushels obtained in Massachusetts in 1920, but are getting none this year (1921); while the Sterling Cider Company use an average of from 8,000 to 10,000 bushels of Massachusetts apples yearly, most of their supply coming from Maine. It is evident that a very large amount of non-marketable apples goes to waste, but it is believed that as time passes more of them will be saved and utilized.

Composition of Dried Apple Pomace.

Table I. — *Composition of Dried Apple Pomace, with Other Carbohydrate Feeds for Comparison.*

No. of Samples.	Feed.	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Total.
6	Dried apple pomace (W. W. Cary & Son).	5.30	1.47	5.57	18.20	65.00	4.46	100.00
6	Apple pomace (local product),[1] .	5.30	3.34	5.57	16.16	64.62	5.01	100.00
38	Dried beet pulp,[2]	9.00	3.00	9.00	18.70	59.60	.70	100.00
193	Corn meal,[3]	12.00	1.30	9.50	2.00	71.50	3.70	100.00

[1] Compilations of analyses. Mass. Agr. Expt. Sta. 1919, p. 11. Reduced to same moisture content for comparison.

[2] *Ibid.*, p. 18.

[3] *Ibid.*, p. 20.

The results of the different analyses showed the product obtained from W. W. Cary & Son to be of quite uniform composition. It is clear that the dried pomace is quite low in protein, containing scarcely 6 per cent, and very high in carbohydrates, approximately 83 per cent, of which some 18 per cent are fiber. The fat indicated by the analyses is more of the nature of waxes and gums than true fat. The ash content of the pomace is comparatively low. The dried pomace compares quite closely in chemical composition with dried beet pulp, except that the latter contains several per cent more protein. It is a carbonaceous feed similar to corn meal, although the latter contains more protein and decidedly less fiber. Although of the same type of composition, the corn meal should be more efficient as a source of energy.

Fuller investigation of the nature of the carbohydrates and protein showed the absence of starch and the presence of considerable amounts of reducing and cane sugars and the hemi-celluloses or pentosans. It was also found that about one-third of the total protein is in the amido form.

A study of the mineral constituents of the dried apple pomace showed that it contains less ash than does beet pulp, and that it is particularly deficient in lime, in which constituent the beet pulp is relatively rich, but contains a fair amount of phosphoric acid and potash.

In calorific value the dried apple pomace compared very favorably with corn meal, sugar and corn starch. Probably the calorific value of the pomace is enhanced by the presence of nearly 5 per cent of waxy material.

Digestibility of Dried Apple Pomace.

In addition to composition, the rate of digestibility is found to throw considerable light upon the nutritive value of a foodstuff, hence eight trials with four different sheep were made, of which seven trials proved to be satisfactory. Four tests were made with the dry, coarse, or unground, pomace; in two cases the pomace was fed with hay, and in two cases with hay and gluten feed, as the basal ration. Three tests were made with the finely ground pomace in which it was fed with hay and gluten feed. The dry, coarse pomace was the product just as it came from the presses; the fine-ground pomace had been passed through an ordinary grist mill and was almost in the form of a powder.

The results showed that the sheep were able to digest on an average 68.5 per cent of the total dry matter in the apple pomace, the fiber and nitrogen-free extract being quite well utilized, the fat to a much less degree,[1] while the protein was apparently not digested at all. We say *apparently* because this peculiarity of indigestibility of protein is often met with in feeds of quite low protein content, and is due to the excretion of nitrogenous material in the form of digestive juices and intestinal wastes. The probability is that the pomace protein, although small in amount, is fairly well utilized.

The trials were not sufficient in number to indicate positively any difference in digestibility between the coarse and the finely ground pomace, and it is doubtful from a nutritive standpoint whether any advantage would be gained in grinding it fine. Compared with other feeds of a similar type, the pomace is shown to be not quite as digestible as dried beet pulp, and much less so than corn meal.

Table II. — *Digestible Matter in 2,000 Pounds.*

Feed.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total Digestible Matter (Fat × 2.25).	Relative Values on Basis of Digestible Matter (Corn meal = 100).
Dried apple pomace,	1,298.0	0	248.8	991.2	32.0	1,312.0	81
Dried beet pulp,	1,365.0	93.6	310.4	989.4	–	1,393.4	87
Corn meal,	1,548.8	127.4	17.6	1,315.6	66.6	1,610.4	100

[1] The fat or other extract is largely in the form of waxy matter and has little nutritive value.

This table shows the dried apple pomace to have almost as much total digestible matter as dried beet pulp, but, as would be expected, considerably less than corn meal. Taking the latter as 100, the pomace has a feeding value of 81 and the beet pulp of 87 per cent. In other words, on the basis of digestibility, if properly fed, one would expect slightly better results from the dried beet pulp and noticeably better results from the corn meal than from the dried pomace.

Net Energy Values.

In place of digestible matter as a measurement of nutritive value, Kellner and also Armsby have adopted the unit of net energy. Net energy means the total energy in the feed minus that excreted in the urine and feces, as well as that lost in heat radiation due to the processes of digestion and assimilation. Armsby expresses it in therms, the therm being the amount of heat required to raise 1,000 kilograms of water 1 degree Centigrade.

Feed.	Net Energy in 100 Pounds (Therms).
Corn meal,	85.17
Dried beet pulp,	75.87
Dried apple pomace,	61.39[1]

[1] Estimated according to Armsby's data for beet pulp and corn meal.

On this basis, with corn meal as 100, beet pulp has a relative value of 89 and apple pomace of 72. Both the figures for digestibility and the net energy values show the apple pomace to be slightly inferior to beet pulp as a source of nutrition.

Dried Apple Pomace for Dairy Cows.

The value of dried apple pomace for milk production was carefully studied during a period extending from Nov. 10, 1920, to May 10, 1921. The material was compared first with dried beet pulp and later with corn meal, on an equal dry-matter basis. The dried pomace was fed moist in both experiments, and was mixed with the grain ration shortly before feeding. It was much relished by the cows. The beet pulp was also moistened.

The experiments were conducted by the usual reversal method, eight cows being used in the first trial and twelve in the second.[1] The animals received the usual care as described in earlier publications of the station. The hay was sampled three times during each half of each experiment by taking forkfuls here and there, running the same through a power cutter and subsampling. The subsamples were placed in glass-stoppered con-

[1] One cow was taken sick halfway through the experiment, and her record is therefore omitted.

tainers and brought at once to the laboratory where moisture determinations were made and composite samples analyzed. The grain was sampled each time a new lot was mixed, and the samples preserved as in the case of the hay. The apple pomace and dried beet pulp were sampled at regular intervals during the experiments. The milk was sampled for five consecutive days three times during each half of each experiment, preserved with formalin, and total solids and fat determined in the usual manner on the composite samples.

The basal ration consisted of a uniform grain mixture plus sufficient hay for the needs of each individual cow. The hay was of only fair quality, some of it being too coarse for good cow hay. With the exception of the corn meal fed in the last experiment, all the concentrates fed were up to the usual standards. The corn meal was unusually low in fat (1.69 per cent), and although bought for meal from whole corn could not have been such, probably having had the germs removed. A definite amount of either apple pomace, beet pulp or corn meal was substituted for a like amount of the basal grain ration, this amount varying with the different individuals in the herd. The basal grain rations fed in the two experiments are shown in the following table: —

Table III. — *Grain Mixtures Fed (Pounds).*

Experiment I. Apple Pomace *v.* Beet Pulp.		Experiment II. Apple Pomace *v.* Corn Meal.	
Bran,	20	Bran,	40
Corn meal,	30	Cottonseed meal,	60
Coconut meal,	30		
Cottonseed meal,	20		

A definite amount of each mixture was given to each animal, — in the first experiment from 6 to 10 pounds daily of I, with from 6 to 7 pounds of either apple pomace or beet pulp; in the second experiment from 5 to 7 pounds daily of II, with from 4 to 5 pounds of either apple pomace or corn meal.

Somewhat less of the basal grain ration was fed to each cow in the second experiment than in the first, and the amount of hay per animal increased, for the reason that it was not considered advisable to feed too large an amount of grain in the corn meal half of the trial.

TABLE IV. — *Average Ration consumed per Cow (Pounds).*

EXPERIMENT I.

Number of Cows.	Character of Ration.	Hay. Total per Cow.	Hay. Daily per Cow.	Apple Pomace. Total per Cow.	Apple Pomace. Daily per Cow.	Beet Pulp. Total per Cow.	Beet Pulp. Daily per Cow.	Grain Mixture. Total per Cow.	Grain Mixture. Daily per Cow.
8	Apple pomace, .	590.63	16.88	231.88	6.63	–	–	284.38	8.13
8	Beet pulp, . .	590.63	16.88	–	–	231.88	6.63	284.38	8.13

EXPERIMENT II.

Number of Cows.	Character of Ration.	Hay. Total per Cow.	Hay. Daily per Cow.	Apple Pomace. Total per Cow.	Apple Pomace. Daily per Cow.	Corn Meal. Total per Cow.	Corn Meal. Daily per Cow.	Grain Mixture. Total per Cow.	Grain Mixture. Daily per Cow.
12	Apple pomace, .	625.00	19.00	157.50	4.50	–	–	218.75	6.25
12	Corn meal, . .	625.00	19.00	–	–	167.65	4.79[1]	218.75	6.25

[1] As the corn meal contained 9 per cent more moisture than the apple pomace, 17 ounces of the former were fed to each pound of the latter.

TABLE V. — *Estimated Dry Matter and Digestible Nutrients in Average Daily Ration (Pounds).*

EXPERIMENT I.

Character of Ration.	Dry Matter.	Digestible Nutrients. Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Apple pomace, .	28.49	1.86	4.14	11.64	.61	18.25	1:9.22[1]
Beet pulp, . .	28.26	2.17	4.37	11.57	.50	18.61	1:7.87

EXPERIMENT II.

Character of Ration.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Apple pomace, .	26.33	2.10	4.33	9.07	.53	16.03	1:6.95[1]
Corn meal, . .	26.16	2.38	3.87	9.94	.53	16.72	1:6.30

[1] Assuming that the protein in apple pomace is 50 per cent digestible, these ratios would be lowered to 1:8.4 and 1:6.4, respectively.

The above figures are based upon analyses and average digestion coefficients. They show that the beet pulp and corn meal rations contained slightly more total digestible nutrients than the corresponding apple pomace ration, and also had narrower nutritive ratios. The former fact is due to the less degree of digestibility of the apple pomace, and the latter fact to its low protein content.

TABLE VI. — *Summary of Yields of Milk and Milk Ingredients (Pounds).*

Experiment.	Character of Ration.	Number of Cows.	Milk produced.	Total Solids.	Total Fat.
I,	Dried apple pomace,	8	7,530.1	973.96	330.19
	Dried beet pulp,		7,775.9	1,020.59	351.54
II,	Dried apple pomace,	11	9,371.8	1,226.52	430.52
	Corn meal,		9,570.4	1,271.73	454.42

TABLE VII. — *Percentage Increase, Beet Pulp or Corn Meal Ration over Apple Pomace Ration.*

Experiment.	Character of Ration.	Milk produced.	Total Solids.	Total Fat.
I,	Dried beet pulp,	3.26	4.79	6.47
II,	Corn meal,	2.12	3.69	5.55

The slightly increased yield produced by the beet pulp over the apple pomace is in no way surprising. It was expected, however, that the corn meal would show a larger increase than did the beet pulp. On the basis of digestibility and net energy estimation it certainly should have proved more effective. If it had been possible to have a larger amount of the total ration composed of the feeds under comparison the results would undoubtedly have been more pronounced.

In Experiment I the cows on both rations showed slight gains in weight. In Experiment II the gain or loss was so insignificant as to be unworthy of consideration.

The general effect of the apple pomace ration was good. At the close of the experiments there was considerable pomace still on hand, and a number of the cows not needed for other work were continued for several months on the same ration as fed in Experiment II. All but one continued in good flesh and gave a satisfactory flow of milk.

How to feed Dried Apple Pomace.

The dried pomace contains very little protein, and if fed in combination with hay, corn silage and corn meal the results are bound to prove unsatisfactory and the feeder will at once conclude that the pomace "dries up the cows." Because it is so ill balanced — that is, so rich in carbohydrates and so lacking in protein — it must be combined with protein feeds in order to secure satisfactory results. It may be fed in two ways, as follows: —

As a Component of the Grain Ration.

I.	Pounds.
Wheat bran or mixed feed,	10
Cottonseed meal,	50
Dried apple pomace,	40

II.	Pounds.
Gluten feed,	30
Cottonseed meal,	30
Dried apple pomace,	40

III.	Pounds.
Corn or corn and cob meal,	10
Cottonseed meal,	50
Dried apple pomace,	40

Feed 1 pound of any of the above mixtures for each 3 pounds of milk produced. It is considered safe to feed at least 4 pounds of the pomace daily in dry condition, providing the cows have frequent access to water.

As a Substitute for Corn Silage.

Seven pounds of kiln dried apple pomace may be fed daily, after being well moistened with water, as a substitute for a bushel of corn silage weighing 30 pounds. It is not advised to feed too large quantities at first, but to begin with 2 or 3 pounds of the dried pomace daily and gradually increase to 7 pounds. It is doubtful if, pound for pound on the same moisture basis, the pomace will prove fully equal in feeding value to well-preserved and well-eared corn silage, but it certainly will approach it. This amount of dried pomace, together with what hay the animal will clean up daily, — 10 to 16 pounds, — may constitute the roughage ration; and in addition the cow should receive from 4 to 10 pounds of a suitable grain mixture, depending upon the ability to profitably utilize it. The following grain mixtures are suggested: —

I.	Pounds.
Cottonseed or linseed meal,	300
Gluten feed or coconut meal,	300
Corn or corn and cob meal or hominy feed or ground oats or barley,	300
Wheat bran,	200
Wheat middlings,	100

II.	Pounds.
Cottonseed or linseed meal,	100
Corn or corn and cob meal, or hominy feed or ground oats or barley,	100
Wheat bran or mixed feed,	100

III.	Pounds.
Gluten feed or coconut meal,	300
Wheat bran or wheat mixed feed,	200
Corn or corn and cob meal or hominy feed or ground oats or barley,	100

IV.	Pounds.
Cottonseed meal,	100
Corn or corn and cob meal,	100

Ration IV is rather less bulky than the other rations, and may be fed mixed more or less with the moistened pomace as a precaution against digestive disturbances.

The Economy of Dried Apple Pomace.

The writer has emphasized for a long time that the farm is primarily the carbohydrate factory upon which maximum amounts of corn and hay should be grown as roughages, supplemented whenever possible with clover, alfalfa and possibly with soy beans. These latter furnish more protein and ash than do the non-legumes, and are favorable to milk production, growth and soil fertility. Purchased feed should be in the form of the protein concentrates; and carbohydrates such as corn, barley, hominy, beet pulp and apple pomace, especially for growth and milk production, should be purchased only when the supply of home-grown feed runs low.

To all intents and purposes, however, apple pomace is a home-grown carbohydrate feed. Through drying, waste of this food resource is prevented. The economy of attempting this conservation depends on its cost. Ultimately the carbohydrate feed produced in this way must be sold at as low a price as is asked for other carbohydrates. Whether this will be possible cannot yet be stated, for the process is still new and the cost factors not fully worked out.

Summary.

Apple pomace is now kiln dried in limited amounts, which insures its preservation and greatly enhances its economic value. It is brownish in color, of a mechanical condition resembling fine shavings, and has a slightly acid taste. Chemical analyses show it to be a strictly carbohydrate feed with a high sugar content and lacking in true starch. It is likewise high in fiber, but quite low in both protein and total ash. Phosphoric acid and potash make up fully 40 per cent of the ash.

Experiments with sheep show it to be fairly well digested, especially with respect to total dry matter, fiber and extract matter. Protein and fat are rather poorly digested, an explanation for this being offered in the text.

For dairy cows, it may be fed to the extent of 4 pounds daily as a component of the grain ration, or 7 pounds daily of the dry material may be well moistened with water and fed as a substitute for a bushel of corn silage.

Experiments herein reported show it to be but slightly inferior to both dried beet pulp and corn meal when fed to dairy cows as a component of the daily ration. No objectionable flavor was noted in the milk, nor was there any bad effect upon the health or condition of the animals.

Fed only with other carbohydrate feeds such as hay, silage and corn, dried apple pomace will prove unsatisfactory. The ration must always be supplemented with rich protein feeds such as cottonseed meal, gluten feed and coconut meal.

The chief use of apple pomace will be as a feed for dairy cows, young stock and sheep. It is of doubtful value for pigs, and as a food for horses it is not recommended.

APPENDIX.

Table VIII. — *Nature of Carbohydrates and Protein of Dried Apple Pomace.*

[Dry matter basis.]

	Per Cent.
Pentosans,	16.09
Galactan,	3.32
Reducing sugars,	13.88
Sucrose,	6.93
Starch,	None.

Total nitrogen,	.93 = 5.80 per cent crude protein.
Albuminoid nitrogen,	.68 = 4.25 per cent true protein.
Amide nitrogen,	.24

Table IX. — *Mineral Constituents of Dried Apple Pomace and Beet Pulp.*

[Dry matter basis.]

	Dried Apple Pomace[1] (Per Cent).	Beet Pulp (Per Cent).
Total ash,	1.607	3.954
Insoluble matter,	.221	.830
Phosphoric acid,	.260	.196
Iron and alumina,	.113	.168
Calcium oxide,	.157	1.007
Magnesium oxide,	.100	.502
Sulfur dioxide,	.034	.465
Potassium oxide,	.506	.301
Sodium oxide,	.037	.140

[1] Analyses made by L. S. Walker of this station.

Table X. — *The Calorific Value of Dried Apple Pomace.*

[Dry Matter Basis.]

	Small Calories per Gram.	Large Calories per Gram.
Dried apple pomace,	4,589	2,082
Corn meal[1] (for comparison),	4,430	2,011
Sugar, guaranteed[1] (for comparison),	3,958	1,753
Corn starch[2] (for comparison),	3,692	1,675

[1] United States Department of Agriculture, Farmers' Bulletin No. 346, by H. P. Armsby, p. 13.

[2] Journal of Agricultural Research, Vol. VII, No. 7, p. 305.

Table XI. — *Digestion Coefficients for Apple Pomace.*

Sheep.

Series.	Experiment	Animal.	Percentages of Ingredients digested. Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Ration Fed.
26, . . .	4	9	63.48	-	0	71.41	73.88	28.35	500 grams hay + 250 grams coarse dry apple pomace.
26, . . .	4	11	68.11	56.25	0	72.93	75.78	40.33	
26, . . .	5	17	71.41	2.53	0	87.08	79.01	43.85	550 grams hay + 150 grams gluten feed + 200 grams coarse dry apple pomace.
26, . . .	5	19	59.45	14.01	0	60.98	71.03	36.10	
Average for the coarse dry or unground pomace,	-	-	65.61	24.26	0	73.10	74.93	37.16	- -
26, . . .	6	9	77.02	94.03	0	80.21	83.87	37.14	500 grams hay + 150 grams gluten feed + 200 grams fine dry apple pomace.
26, . . .	6	11	65.49	53.84	0	58.61	75.45	25.22	
26,[1] . . .	8	19	71.82	107.14	0	52.13	73.39	41.38	550 grams hay + 150 grams gluten feed + 200 grams fine dry apple pomace.
Average for the fine dry or ground pomace, . .	-	-	71.44	84.67	0	63.65	77.57	34.58	- -
Average of above seven single trials,	-	-	68.53	54.47	0	68.38	76.25	35.87	- -
Average of six previous single trials (wet pomace),[2] .	-	-	72.00	49.00	0	65.00	85.00	46.00	- -
Dried beet pulp, .	-	-	75.00	26.00	52.00	83.00	83.00	-	- -
Corn meal, . .	-	-	88.00	-	67.00	44.00	92.00	90.00	- -

[1] Sheep No. 17 did not eat well in this trial and had to be rejected.

[2] Seventeenth annual report, Hatch Experiment Station, Amherst, Mass., p. 86.

Tabulated Data of the Experiments with Dairy Cows.

Table XII. — *History of the Cows.*

Experiment I.

Name.	Age.	Breed.	Calved.	Served.	Daily Milk Yield, Beginning (Pounds).	Fat (Per Cent).
Fancy V, . .	3	Grade Jersey, .	Aug. 23, 1920	Jan. 6, 1921	22	4.9
Samantha III, .	7	Grade Holstein,	Sept. 18, 1920	Dec. 15, 1920	34	4.6
Samantha IV, .	6	Grade Holstein,	Sept. 11, 1920	Nov. 13, 1920	34	4.0
190, . . .	-	Grade Holstein,	Oct. 15, 1920	Jan. 15, 1921	27	3.8
Fancy IV, . .	6	Grade Jersey, .	Aug. 15, 1920	Jan. 6, 1921	18	5.0
46, . . .	8	Grade Holstein,	Sept. 18, 1920	Nov. 10, 1920	41	3.7
Colantha II, .	6	Grade Holstein,	Aug. 10, 1920	Nov. 18, 1920	34	4.4
Colantha IV, .	3	Grade Holstein,	Oct. 18, 1920	Feb. 7, 1921	25	3.7

TABLE XII. — *History of the Cows* — Concluded.

EXPERIMENT II.

NAME.	Age.	Breed.	Calved.	Served.	Daily Milk Yield, Beginning (Pounds).	Fat (Per Cent).
Fancy IV,	7	Grade Jersey,	Aug. 15, 1920	Nov. 17, 1920	16	5.9
46,	8	Grade Holstein,	Sept. 18, 1920	Nov. 10, 1920	35	3.2
Colantha II,	6	Grade Holstein,	Aug. 10, 1920	Nov. 18, 1920	32	4.9
Colantha IV,	3	Grade Holstein,	Oct. 18, 1920	Dec. 11, 1920	24	3.7
Ida II,	8	Jersey,	Nov. 14, 1920	Jan. 6, 1921	24	5.5
Red IV,	7	Grade Jersey,	Dec. 31, 1920	–[1]	32	5.3
Fancy V,	4	Grade Jersey,	Aug. 23, 1920	Jan. 6, 1921	21	6.0
Samantha III,	7	Grade Holstein,	Sept. 18, 1920	Dec. 15, 1920	30	4.9
Samantha IV,	6	Grade Holstein,	Sept. 11, 1920	Nov. 13, 1920	33	4.6
190,	–	Grade Holstein,	Oct. 18, 1920	Jan. 21, 1921	28	3.9
Peggy,	10	Grade Jersey,	Nov. 11, 1920	Dec. 9, 1920	25	5.6
Cecile II,	8	Jersey,	Nov. 30, 1920	–[1]	25	5.1

[1] Not bred.

TABLE XIII. — *Chemical Analyses of Feeds Used (Per Cent).*

EXPERIMENT.	Feed.	Water.	Ash.	Crude Protein.	Fiber.	Extract Matter.	Fat.
I,		9.25–12.75					
	Hay,	11.38	5.17	6.59	29.15	45.78	1.93
	Apple pomace,	5.45	1.48	5.48	17.90	65.26	4.42
	Beet pulp,	8.87	3.96	9.10	18.95	58.41	.69
	Grain mixture,	10.75	4.43	19.45	8.20	52.12	5.04
II,		11.53–16.88					
	Hay,	13.44	5.25	7.22	30.03	42.08	1.98
	Apple pomace,	6.21	1.46	5.49	16.69	65.72	4.44
	Corn meal,[1]	15.54	1.29	8.61	2.01	70.85	1.69
	Grain mixture,	9.44	6.16	27.68	11.52	39.71	5.49

[1] The corn meal was unusually low in fat (1.69%), and although bought for meal from whole corn, could not have been such, probably having had the germs removed.

TABLE XIV. — *Duration of Experiments.*

EXPERIMENT I.

DATES.	Basal Ration+Apple Pomace.	Basal Ration+Dried Beet Pulp.	Weeks fed.
Nov. 22, 1920, to Dec. 26, 1920, inclusive,	Fancy V, Samantha III, Samantha IV, 190,	Fancy IV, 46, Colantha II, Colantha IV,	5
Jan. 6, 1921, to Feb. 9, 1921, inclusive,	Fancy IV, 46, Colantha II, Colantha IV,	Fancy V, Samantha III, Samantha IV, 190,	5

Table XIV. — *Duration of Experiments* — Concluded.

Experiment II.

Dates.	Basal Ration+Apple Pomace.	Basal Ration+Corn Meal.	Weeks fed.
Feb. 20, 1921, to March 26, 1921, inclusive,	Fancy IV, 46, Colantha II, Colantha IV, Ida II, Red IV,	Fancy V, Samantha III[1], Samantha IV, 190, Peggy, Cecile,	5
April 6, 1921, to May 10, 1921, inclusive,	Fancy V, –[1] Samantha IV, 190, Peggy, Cecile,	Fancy IV, 46, Colantha II, Colantha IV, Ida II, Red IV,	5

[1] Samantha III was taken sick halfway through the experiment and had to be discontinued. Her record is therefore omitted for the entire experiment.

Table XV. — *Gain or Loss in Live Weight (Pounds).*

Experiment.	Gain.		Loss.		Net.	
	Apple Pomace.	Beet Pulp.	Apple Pomace.	Beet Pulp.	Apple Pomace.	Beet Pulp.
I,	156	195	3	0	153+	195+

Experiment.	Gain.		Loss.		Net.	
	Apple Pomace.	Corn Meal.	Apple Pomace.	Corn Meal.	Apple Pomace.	Corn Meal.
II,	94	90	73	113	21+	23−

Table XVI. — *Total Yields of Milk and Milk Ingredients.*

Experiment I.

Apple Pomace Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy V,	742.4	14.87	110.39	5.86	43.50
Samantha III,	1,014.6	13.74	139.41	4.94	50.12
Samantha IV,	968.8	12.74	123.43	4.54	43.98
190,	971.8	12.28	119.34	3.84	37.32
Fancy IV,	548.8	15.15	83.14	5.74	31.50
46,	1,279.7	10.93	139.87	3.04	38.90
Colantha II,	1,110.2	13.58	150.77	4.73	52.51
Colantha IV,	893.8	12.04	107.61	3.62	32.36
Totals,	7,530.1	–	973.96	–	330.19
Averages,	–	12.93[1]	–	4.38[1]	–

[1] Average percentage of solids and fat obtained by dividing total pounds of each by total milk yield.

TABLE XVI. — *Total Yields of Milk and Milk Ingredients* — Concluded.

EXPERIMENT I — *Concluded.*

Beet Pulp Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy V,	726.7	15.59	113.29	6.24	45.35
Samantha III,	1,033.1	13.98	144.43	4.99	51.55
Samantha IV,	1,144.0	13.10	149.86	4.70	53.77
190,	1,014.5	12.64	128.23	4.13	41.90
Fancy IV,	610.1	15.15	92.43	5.82	35.51
46,	1,413.4	11.12	157.17	3.17	44.80
Colantha II,	877.8	13.61	119.47	4.81	42.22
Colantha IV,	956.3	12.10	115.71	3.81	36.44
Totals,	7,775.9	–	1,020.59	–	351.54
Averages,	–	13.12[1]	–	4.52[1]	–

EXPERIMENT II.

Apple Pomace Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy IV,	524.6	14.52	76.17	5.33	27.96
46,	1,079.1	11.18	120.64	3.29	35.50
Colantha II,	1,065.8	13.01	138.66	4.44	47.32
Colantha IV,	824.6	11.83	97.55	3.66	30.18
Ida II,	829.3	14.02	116.27	5.12	42.46
Red IV,	1,083.0	13.16	142.52	4.80	51.98
Fancy V,	677.6	14.55	98.59	5.51	37.34
Samantha IV,	987.8	12.80	126.44	4.51	44.55
190,	814.4	12.54	102.13	4.17	33.96
Peggy,	747.9	14.12	105.60	5.45	40.76
Cecile II,	737.7	13.82	101.95	5.22	38.51
Totals,	9,371.8	–	1,226.52	–	430.52
Averages,	–	13.09[1]	–	4.59[1]	–

Corn Meal Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy IV,	547.3	14.91	81.60	5.63	30.81
46,	912.6	12.03	109.79	3.51	32.03
Colantha II,	893.1	12.83	114.58	4.74	42.33
Colantha IV,	839.5	12.12	101.75	3.51	29.47
Ida II,	800.0	14.03	112.24	5.33	42.64
Red IV,	1,022.3	13.69	139.95	5.13	52.44
Fancy V,	728.7	14.78	107.70	5.68	41.39
Samantha IV,	1,166.1	12.77	148.91	4.48	52.24
190,	930.7	12.26	114.10	4.08	37.97
Peggy,	871.5	14.10	122.88	5.60	48.80
Cecile II,	858.6	13.77	118.23	5.16	44.30
Totals,	9,570.4	–	1,271.73	–	454.42
Averages,	–	12.29[1]	–	4.75[1]	–

[1] Average percentage of solids and fat obtained by dividing total pounds of each by total milk yield.

BULLETIN NO. 206.

REPORT OF THE CRANBERRY STATION FOR 1919 AND 1920.

BY H. J. FRANKLIN.

The cranberry industry in southeastern Massachusetts, particularly in Barnstable and Plymouth counties, is the most marked feature of the agriculture of that region. It has given large value to some 14,000 acres of peat and muck soils which previously had little or no value, having made mosquito-breeding swamps into agriculturally productive land. It gives seasonal employment to many hundreds of workers, and it adds from two to three million dollars to the value of the agricultural products of the section annually. The cranberry is the most important export crop of the State.

It is thus apparent that anything which injures the cranberry industry affects not only the sections in which the berries are grown but also the Commonwealth as a whole. Partial crop failures, whatever the cause, result in severe loss, both to the bog owners and operators and to the laborers who are accustomed to secure a part of their livelihood by work on the bogs. Reduction of the crop lessens the ability of the community to meet its taxes; it also decreases the purchasing power of the section and so affects other industries. It was to develop methods of avoiding such partial crop failures that the State in 1910 established the Cranberry Station of the Experiment Station.

For ten years the Cranberry Station has been in operation. It has given major attention to the study of the insects which injuriously affect the cranberry crop. It has also investigated the problems of plant disease control, bog fertilization, berry storage, frost protection, cranberry varieties, and even the possibilities of the blueberry as a companion crop to cranberries. In addition, the Cranberry Station has served as a center for growers' meetings, and the services of the specialist in charge in an advisory capacity have been widely sought by the growers. The following report is the eighth of the Cranberry Station, and is a discussion of the more important results of the work of 1919 and 1920.

Field Meetings.

In early June, 1920, five field meetings were held (in Rochester, Carver, Plymouth, Wareham and Sandwich) with cranberry growers to demonstrate the use of the insect net in discovering and gauging certain insect infestations in their early stages. These meetings were planned as a special effort in the control of the gypsy moth, but the other open-feeding caterpillars often harmful to bogs, such as spanworms and false army worms, were also discussed. A supply of nets had been prepared and sixty were sold to growers.

Frost Predictions.

In both 1919 and 1920 much progress was made in perfecting methods of frost predicting. Most of the results of this study and of the frost investigations of previous years are given in a paper lately published.[1] In 1920 arrangements were made with the New England Telephone and Telegraph Company for distributing frost predictions to be sent out by the station in the early afternoon and early evening. This service began in the fall.

Study of Cranberry Varieties.

The study of the characteristics of the Cape cranberry varieties was continued, special attention being given to seed counts. Small plantings of the Pride and Wales Henry varieties were made at the station in the spring of 1920.

Additions to Station Equipment.

In 1919 a lean-to shed, 41 by 20 feet, with a concrete floor, corrugated iron sides, and board and paper roof, was added to the station building. In one end of this, a part 11½ by 20 feet was made into a garage, the larger room being for box and barrel storage. This addition had long been needed, for when the bog produced a large crop the building was too crowded for storage tests.

A screening belt and a Ford runabout truck also were added to the station equipment in 1919. The latter, presented by the Cape Cod Cranberry Growers' Association, was especially helpful, making it possible to visit bogs in distant towns more freely. This extension of the field of operations not only made the station more serviceable to the growers, but also yielded valuable results in the way of new observations.

Yields in 1919 and 1920.

The station bog yielded scantily in 1919 for reasons given below, only about 80 barrels of berries being sold, and this fruit of poor quality. On this account, keeping tests were mostly omitted that year. In 1920 the bog

[1] Monthly Weather Review Supplement No. 16: 20–30, 1920.

produced 909 barrels of unusually sound berries which sold for about $7,300.

The spring and early summer of 1920 on the Cape were wet and backward. Because of the rains, there were a few hundred acres from which it was impossible to remove the winter water early enough to grow a crop, the importance of adequate drainage thus being emphasized again.

In 1920 most of the Cape bogs bloomed very heavily and so aroused the anticipation of a record crop, but there was a marked and widespread failure to set fruit, and the total Cape yield was only about 277,000 barrels. The weather and blossom conditions and the fruiting failure paralleled those of 1916,[1] except that thin vines were not relatively more fruitful.

Fungous Diseases.

The "Rosebloom" Disease.

As the "rosebloom" disease (*Exobasidium oxycocci*) had greatly reduced the crop of Howes and McFarlin berries on the station bog for three successive years, treatment by flooding was tried in 1919. The winter flood was let off March 23, and the shoots enlarged by the disease became partly grown and abundant by May 25 when the first reflooding was done. The water was held sixty hours, the weather being mostly clear. The diseased shoots collapsed and dried up within a day after the flood was let off. More such shoots grew later and were killed by the mid-June flowage mentioned below. Little evidence of the disease appeared on the bog the rest of the season, and comparatively few of the enlarged shoots grew in 1920, the treatment thus seeming to have been largely successful. The early destruction of the diseased growths probably reduced the spore production of the fungus greatly, and thus lessened the infection of the new axillary buds.

Wisconsin False Blossom.

False blossom (the Wisconsin disease) has previously been reported[2] as found on five Cape bogs, the infestation being due to planting Wisconsin vines in every case. All these infestations have been wiped out by destroying the infected vines. In the fall of 1919 six heretofore unnoticed infestations were found by Dr. Stevens of the Bureau of Plant Industry and the writer on Holliston[3] vines in Pembroke, Carver and Wareham. The histories of the plantings strongly suggested that all the infections had had a common origin on a bog in Wareham, where the variety had been known as "Small's No. 1." Holliston vines on ten other bogs, in Plymouth, Carver, Middleborough, Lakeville, South Hanover and Holliston, the planting in the last-named town being the original one of the variety, showed no sign of the disease. This suggests that the Holliston variety, as grown on the Cape, may be a double one, the infected strain

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[1] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 184.

[2] Mass. Agr. Expt. Sta., Bul. No. 160, 1915, p. 100; and Bul. No. 168, 1916, p. 5.

[3] This variety is widely known as "Mammoth" or "Batchelder," but the name of its place of origin seems preferable.

perhaps having come from Wisconsin. The Bennet Jumbo variety resembles the Holliston. The fact that Holliston vines are widely infected warns against further planting of the variety.

Early Black and Howes vines much affected by false blossom were found on two bogs in Marion. The vines of these plantings came from several sources and the origin of the infection is uncertain. This disease evidently is more widely prevalent on the Cape than has been supposed. Those who start new plantings should be careful not to use vines harboring it.

Fungous Injury to Small Berries caused by Submergence.

In late July and early August, 1919, numerous tests were conducted to determine the effect of submergence on the small berries. Pieces of cranberry turf, with the vines bearing berries, were immersed in Spectacle Pond (East Wareham) in clear or mostly clear weather. The periods of submersion were one to four days long. Early Black and Howes berries from various bogs were tested comparatively in this way several times. Pride and Perry Red berries also were tried. In all cases the Howes fruit was hurt less by the submersion than that of the other varieties. It appeared that this variety usually can be flooded forty-eight hours in clear weather, while the berries are small, without serious immediate harm. Such treatment probably would impair keeping quality, however. The results with the Early Black berries varied greatly, some lots being much harmed by twenty-four hours of submersion, while others seemed little hurt after forty-eight hours; but generally this variety was the most susceptible to injury of those treated, the Pride and Perry Red being intermediate. The water did most harm when its temperature was relatively high. Some Howes lots showed but little softening when submerged in cool weather four days.

Injury incidental to submergence seemed due to rapid development of putrefactive fungi. The softening of the berry always started in a small spot which kept enlarging as long as the immersion continued, until it included the whole fruit. The softened tissue examined microscopically was found always full of mycelium.

Dr. C. L. Shear, of the Bureau of Plant Industry, and his assistants, made cultures from the softened tissues of various lots of berries from these tests. The fungi found and their relative abundance are shown in Table 1.

Table 1. — *Fungi found in Fruit of Summer Immersion Tests.*

Fungi.	Early Black.	Perry Red.	Pride.	Howes.	Totals.
Dematium,	2½	2	2	1	7½
Fusicoccum putrefaciens Shear,	2½	0	0	2½	5
Phomopsis,	½	0	3	0	3½
Sporonema oxycocci Shear,	2½	1	0	0	3
Penicillium sp.,	0	1	2	0	3
Pestalozzia guepini vaccinii Shear,	1	1	0	0	2
Glomerella cingulata,	1	0	0	½	1½
Acanthorhynchus vaccinii Shear,	0	0	1	0	1
Altenaria,	½	0	0	0	½
Undetermined,	1½	5	2	5	13½

The totals of the table show that most of the softening of the berries was caused by the first five fungi, and that the first two were the most active.

Spraying for the Control of Fungous Diseases.

Tables 2, 3 and 4 show the results of spraying Early Black vines with "Corona" lead arsenate used at the rate of 4 pounds to 50 gallons of water, without soap. The plots of Tables 2 and 3 were the same areas, respectively, so numbered in 1918.[1] In 1919, plots A. L. 3 and A. L. 4 were treated on June 24 and July 11; A. L. 5 on June 23, July 12 and 31; and A. L. 7 on June 24, July 11 and 24. All the plots of Tables 3 and 4 were sprayed on June 23, July 26 and August 20. The quantity of fruit stored in 1919 varied from 1 to 4 bushels for each plot or check. In 1920, 6 or 7 bushels were stored for each area of Table 3, and from 2 to 7 bushels for each area of Table 4. The effect of this spraying, shown by the percentages in the tables, except possibly those of plot B, confirms the results of like tests in previous years.[2]

[1] Mass. Agr. Expt. Sta., Bul. No. 192, 1919, p. 107.

[2] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, pp. 189–192; Bul. No. 192, 1919, pp. 106, 107.

TABLE 2. — *Station Bog Early Black Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1919.*

Plots and Checks.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
A. L. 3,	9	.41	Sept. 16 to Dec. 12	34.39
Check 1,	6	.56	Sept. 16 to Dec. 12	47.34
Check 2,	9	.53	Sept. 16 to Dec. 12	48.11
A. L. 4,	8	.38	Sept. 16 to Dec. 11	37.14
Check 1,	8	.50	Sept. 16 to Dec. 11	41.38
Check 2,	8	.38	Sept. 16 to Dec. 13	49.98
A. L. 5,	–	–	Sept. 16 to Dec. 12	43.01
Check 1,	–	–	Sept. 16 to Dec. 12	57.82
Check 2,	–	–	Sept. 16 to Dec. 11	63.65
Check 3,	–	–	Sept. 16 to Dec. 11	65.07
A. L. 7,	8	.25	Sept. 16 to Dec. 11	47.11
Check 1,	8	.13	Sept. 16 to Dec. 11	63.56
Check 2,	8	.22	Sept. 16 to Dec. 11	60.04

TABLE 3. — *Station Bog Early Black Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1920.*

Plots and Checks.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
A. L. 1,	9	1.30	Sept. 18 to Dec. 3	12.06
Check 1,	6	1.33	Sept. 18 to Dec. 4	18.09
Check 2,	6	1.44	Sept. 18 to Dec. 3	24.56
Check 3,	6	1.61	Sept. 18 to Dec. 3	19.02
A. L. 2,	9	1.50	Sept. 27 to Dec. 7	18.26
Check 1,	6	1.42	Sept. 27 to Dec. 7	28.30
Check 2,	6	1.63	Sept. 27 to Dec. 7	26.35
Check 3,	6	1.92	Sept. 27 to Dec. 7	32.02
A. L. 3,	9	1.74	Sept. 27 to Dec. 6	9.88
Check 1,	6	1.86	Sept. 27 to Dec. 6	22.73
Check 2,	6	1.96	Sept. 27 to Dec. 6	25.13
A. L. 4,	8	1.70	Sept. 27 to Dec. 4	9.39
Check 1,	6	2.21	Sept. 27 to Dec. 6	25.04
Check 2,	8	2.04	Sept. 27 to Dec. 6	23.55
A. L. 5,	9	1.31	Sept. 18 to Dec. 3	8.74
Check 1,	9	1.37	Sept. 18 to Dec. 4	18.45
Check 2,	6	1.11	Sept. 18 to Dec. 3	17.96
Check 3,	6	1.15	Sept. 18 to Dec. 2	17.78
A. L. 7,	8	1.06	Sept. 18 to Nov. 30	5.27
Check 1,	8	1.06	Sept. 18 to Nov. 29	20.47
Check 2,	4	.81	Sept. 18 to Nov. 29	15.34
Check 3,	8	1.13	Sept. 18 to Nov. 30	19.17

TABLE 4. — *Eagle Holt Bog Early Black Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1920.*

Plots and Checks.	Storage Period.	Percentage of Berries showing Decay at End of Storage.
Plot A,	Oct. to Nov. 27,	9.61
Check,	Oct. 1 to Nov. 29,	19.96
Plot B,	Sept. 10 to Nov. 26,	20.88
Check 1,	Sept. 10 to Nov. 26,	21.89
Check 2,	Sept. 10 to Nov. 26,	22.23
Check 3,	Sept. 10 to Nov. 26	22.71

The plots of Table 5 were treated in the same way and on the same dates as those of Tables 3 and 4. The results with the first plot were like those with the Early Black variety, but the fruit of the second plot showed no effect from the spraying.

TABLE 5. — *Station Bog Howes Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1920.*

Plots and Checks.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
Howes A. L. 1,	9	.74	Oct. 2 to Dec. 9	5.92
Check 1,	6	.42	Oct. 2 to Dec. 9	8.78
Check 2,	4½	.74	Oct. 2 to Dec. 9	8.61
Check 3,	9	.93	Oct. 2 to Dec. 8	8.80
Howes A. L. 2,	9	1.43	Oct. 2 to Dec. 9	14.66
Check 1,	9	1.07	Oct. 2 to Dec. 9	13.69
Check 2,	6	.94	Oct. 2 to Dec. 8	14.98
Check 3,	9	1.22	Oct. 2 to Dec. 9	10.09

Table 6 shows that two Early Black plots gave a reaction to calcium arsenate like that produced by lead arsenate. These plots were sprayed June 22, July 27 and August 20, the insecticide being used at the rate of 4 pounds to 50 gallons of water, without soap. Five or 6 bushels of fruit from each of these plots and each check were stored.

TABLE 6. — *Station Bog Early Black Spraying Plots (Fungous Diseases) treated with Calcium Arsenate, 1920.*

PLOTS AND CHECKS.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
A. Lime 1,	6	1.63	Sept. 27 to Dec. 6	20.85
Check,	6	1.94	Sept. 27 to Dec. 7	28.06
A. Lime 2,	6	1.39	Sept. 27 to Dec. 4	10.63
Check,	6	1.58	Sept. 27 to Dec. 1	16.52

With all the spraying plots having more than one check, the checks bordered different sides of the plot. The berries were all scoop-picked and stored in bushel crates as they came from the bog. At the end of the storage the fruit was examined by the "seven-sample" method[1] by the screeners employed at the station, under the writer's supervision, the inspector's cup of the New England Cranberry Sales Company being used for sampling. The Sales Company's hand grader was used to facilitate the work.

In both 1919 and 1920 the vines sprayed repeatedly with lead arsenate for three or more years had such a growth of runners that they were hard to scoop. As the surrounding bog showed no such development, this was clearly a reaction to the insecticide. The sprayed vines seemed to show a slight reduction in number of uprights. On the whole, the effect of the spraying on the vines was distinctly undesirable.

In 1920 Dr. Shear and his assistants made cultures of the fungi in twenty rotten berries taken at random at the end of the storage period from among the fruit of each of three of the lead arsenate plots and the fruit of the checks on each of these plots. Table 7 shows what fungi were found. Apparently the spraying had reduced both Phomopsis and *Fusicoccum putrefaciens* greatly, and had affected Glomerella, Sporonema and Dematium little, if any. These conclusions are supported by the fact that mostly negative results have been obtained in spraying Howes vines with lead arsenate, for studies in previous seasons[2] showed that on the station bog Glomerella was relatively a much more important disease of the Howes variety than of the Early Black.

[1] In this method seven samples from each crate are examined, one being taken from the surface berries of each half of the crate halfway between the middle and end; one from each half of the crate halfway between the top and bottom and halfway between the center and end; one from the very center; and one from the very bottom of each half of the crate halfway between the middle and end.

[2] Mass. Agr. Expt. Sta., Bul. No. 198, 1920, pp. 88–92.

TABLE 7. — *The Number of Cultures of Different Fungi obtained from Decayed Berries from Sprayed Areas and their Unsprayed Checks.*

Fungi.	Number of Berries giving Cultures of the Fungi.[1]							
	Sprayed Plots.				Check Plots (not sprayed).			
	A. L. 2.	A. L. 5.	A. L. 7.	Totals of the Three Plots.	Checks on A. L. 2.	Checks on A. L. 5.	Checks on A. L. 7.	Totals of the Checks.
Fusicoccum, . .	2	8	8	18	8	11	15	34
Glomerella, . .	11	9	7	27	3	5	2	10
Phomopsis, . .	0	1	1	2	2	3	5	10
Sporonema, . .	0	2	7	9	0	4	1	5
Penicillium, . .	2	0	3	5	2	1	0	3
Dematium, . .	2	1	1	4	1	0	0	1
Alternaria, . .	0	0	0	0	2	0	0	2

[1] In each case cultures were made from twenty rotten berries.

Keeping Tests with the Pride Variety.

As the Pride is the most productive cranberry variety and is not widely grown, knowledge of the keeping quality of its fruit is desirable. In a test made in a previous year this variety seemed superior to the Early Black and not greatly inferior to the Howes. In 1919 a shipping test was conducted, Early Black berries being provided by the station, three Pride lots by B. F. Vose, L. B. Handy and the Federal Cranberry Company, respectively, and two Howes lots by C. R. Rogers. Each lot consisted of one barrel of berries. All the fruit was separated, screened and packed under uniform conditions at the Carver packing house of the New England Cranberry Sales Company. It was shipped to Washington, D. C., and there stored and examined under the direction of Drs. Shear and Stevens. The results appear in Table 8.

TABLE 8. — *Results of Keeping Test of Cranberries, 1919.*

[The berries were screened at North Carver October 16, received at Washington, D. C., October 24, and stored at a temperature of 40 to 50° F. until the date given. Note that the Early Blacks and the first lot of Prides were sorted a week before the rest.]

Barrel Samples.	Percentage of Sound Berries.					
	Station **Early Blacks** (Sorted Nov. 15).	Handy **Prides** (Sorted Nov. 15).	Federal **Prides** (Sorted Nov. 22).	Vose **Prides** (Sorted Nov. 22).	Rogers **Howes** (Sorted Nov. 22).	Rogers **Howes** (Sorted Nov. 22).
Top, ...	41	80	56	70	72	84
¼, ...	39	65	52	70	77	85
¼, ...	33	65	58	84	75	84
Middle, ...	41	69	55	70	79	80
Middle, ...	52	73	50	63	76	88
¾, ...	36	60	61	63	80	82
¾, ...	39	69	58	68	89	82
Bottom, ...	49	71	60	76	83	81
Average, . . .	41	69	56	71	79	83

Insects.

The Green Spanworm (*Cymatophora sulphurea* (Pack.)).

This species was unusually prevalent in 1920, the moths appearing abundantly on many bogs and the worms wiping out a fine crop promise on several bogs in Duxbury.

The moths were flying in clouds on the Duxbury bog on July 22 and also on August 2. On the former date the males outnumbered the females fully 200 to 1, while on the latter they seemed only slightly more numerous. This indicates that the species is strongly protandrous in emerging from the pupa. The males are more active than the females, but both sexes rest much among the vines. The males fly much less than those of *Epelis truncataria*, but they are flushed up easily. Several females reared in confinement and dissected before they oviposited contained from 103 to 117 eggs. The greater egg capacity of *Epelis* [1] may explain its greater prevalence. Green spanworms captured August 2 were found to be mostly through laying. The greenish-white eggs are laid singly on the old fallen leaves under the vines, and winter under the water (if the bog is flooded), hatching in the spring.

The injury done on the Duxbury bog was much like the work of the blossom worm [2] (or bud worm), the flowers being nipped off and dropped.

The Brown Spanworm (*Epelis truncataria var. faxonii* Minot).

This species was found in great numbers on twelve different bogs in 1919, and the moths appeared abundantly on even more in 1920. It was so much more prevalent than usual that it demanded as much attention as any cranberry pest except the gypsy moth. The writer attended to many requests for advice in checking infestations in 1920, and the insect did little harm except on a few neglected bogs, lead arsenate (3 pounds of powder to 50 gallons of water) being very effective wherever used.

The worms began hatching June 30, 1919, and July 1, 1920, probably being about normal in this respect both years. In 1919 they worked on some bogs until into August. Uncounted hundreds over a thousand of the small worms to 50 sweeps of an insect net were obtained on parts of one bog two days after hatching began there. This bog was sprayed with lead arsenate at once. It was examined again sixteen days later and 75 nearly mature worms to 50 sweeps of the net were obtained on the area most infested. These caterpillars were doing little harm, for the only notable injury on the vines was the work of the multitude of small worms that had been checked by the spraying soon after they began. The tips of the vines had made much new growth after the spraying. This was lighter green than the earlier growth of the season and showed little worm-eating. This and other observations have shown that an infestation of this insect giving less than 50 worms to 50 sweeps of the net will not do much harm

[1] Mass. Agr. Expt. Sta., Bul. No. 150, 1914, p. 50.
[2] U. S. Dept. Agr., Farmers' Bul. No. 860, 1917, p. 23.

when not treated. With such a light attack, it may not pay to spray if the bloom is heavy and the crop prospect good, because of the mechanical injury done in spraying. If the crop promise is poor, however, it is best to treat even a light infestation to save trouble the next year. The writer observed a case in which an infestation giving 275 worms to 50 sweeps of the net destroyed fully three-fourths of a fine prospective crop. One experienced with this pest can gauge a coming attack fairly well by the numbers in which the moths appear in mid-June.

The spraying should be done when the eggs begin to hatch, for the worms are poisoned most easily in their first stages, and they are sometimes numerous enough to destroy a fine crop promise within four days after hatching begins. Therefore an infested bog should be examined with an insect net daily from June 20 until the worms are found. If the infestation is severe and the area involved is so large that it will take several days to treat it, the spraying should begin a few days before the worms are expected, and the less heavily infested vines should be treated first. Under such conditions the work usually should start about June 26 on bogs from which the winter water has been let off before May 5.

The small worms seem usually to attack the flower buds as soon as anything, a hole commonly being eaten through the ovary. Often in moderate infestations they work like the blossom worm mentioned above, the flowers being nipped off and dropped to the ground.

When this species attacks severely enough to turn the vines brown it always destroys all chances of a crop in the following year, even if it is completely controlled that season, and sometimes patches of vines fail to recover for two or three years.

The period of activity of the green spanworm moths coincides with that of the worms of this insect, and as both species often abound on the same area, they are much confused in the minds of growers.

The Cranberry Girdler (*Crambus hortuellus* Hübner).

This pest was much more prevalent, especially in 1920, than it had been for many years. Its increase was pretty certainly due to the general neglect of resanding during and since the war.

Hitherto unreported parasites of the girdler were reared, as follows: —

1. *Cremastus facilis* (Cress.).[1] This species makes a delicate brownish-gray cocoon inside that of its host. Apparently no girdler cocoon ever contains more than one of these parasites. The adult parasites emerged June 6 and 7, 1919, from cocoons collected on a bog the former day. About 10 per cent of the cocoons harbored this parasite.

2. *Macrocentrus* sp.[1] Several cocoons of this species were found together in each of two host cocoons collected on a bog May 31, 1919. The adults emerged from one to four days later.

3. *Phygadeuon* sp.[1] The cocoons of this parasite are yellow and astonishingly tough. As with *Cremastus*, there is but one in a host cocoon.

[1] Identified by R. A. Cushman of the Bureau of Entomology.

Girdler cocoons containing cocoons of this species were collected on a bog June 6, 1919, and the adult parasites emerged May 10 and 11, 1920, their cocoon stage thus being remarkably long. It was estimated that about 10 per cent of the girdler cocoons on the bog from which these specimens came contained this parasite.

The girdler cocoons from which these three parasite species emerged were collected at South Wareham, on a bog which always is flooded in the winter and usually is flowed for a day or two in June. They were taken from an area, about 80 yards from the bog margin, from which the vines had been burned off in early May, before the thick accumulation of old fallen leaves on the ground had dried out. The burning had been done to destroy the girdler infestation, but it had not killed either this pest or the brown spanworm (*Epelis*), pupæ of which were present in some numbers.

The writer often finds barn swallows capturing large numbers of girdler moths.[1]

It was found in 1920 that 1 part of Black-Leaf 40 in 400 parts of water, with 2 pounds of soap to 50 gallons added, kills girdler moths readily. While this spray may not control the pest entirely, it probably will help greatly where other means are lacking. It probably should be used about four times, at three-day intervals, for the moths emerge from their cocoons in large numbers for a week or two. The insecticide, tried in this connection at strengths of 1 to 600 and 1 to 800 with soap, and 1 to 400 without soap, proved unsatisfactory.

The Cranberry Root Grub (*Amphicoma vulpina* Hentz.).

On July 21, 1917, some wash boilers with the bottoms removed were driven into the station bog until the vines came within a few inches of their tops. Grubs of this species gathered from another bog were put in them as follows, after which the boilers were covered tightly with cheesecloth for the rest of the summer.

TABLE 9. — *Root Grubs put in Boilers at Station Bog July 22, 1917.*

BOILER NO.	Number of Grubs.	Length of Grubs[2] (Millimeters).
1,	17	8–10
2,	60	12–15
3,	21	15–20
4,	97	20–28
5,	60	28–30

[1] Forbush: Useful Birds and Their Protection, p. 346, 1907. U. S. Dept. Agr., Bul. No. 554, 1917, p. 12.

[2] The grubs of various sizes were found working together, as is common with this species, broods started in two or three different years probably being represented.

On July 8, 1919, the vines inside the boilers were removed and the sand down to the peat, about 7 inches deep, was taken out and carefully sifted. Amphicoma grubs were found as follows: —

Table 10. — *Root Grubs found in Boilers at Station Bog July 8, 1919.*

Boiler No.	Number of Grubs found.	Length of Grubs (Millimeters).
1,	2	24–25
2,	5	21–25
3,	1	26
4,	5	9–11
5,	0	–

The grubs from the first three boilers were evidently what were left of those put in in 1917, larger grown. Those from boiler 4 probably were a new brood produced by beetles of the grubs put in in 1917. Grubs of the smaller sizes probably were a year or more old when put in the boilers in 1917, and the size of those taken from boilers 1, 2 and 3 in 1919 suggests that they required another year to mature. Evidently, therefore. the grub stage lasts three or four years.

On July 1, 1920, the grubs were found in numbers among the fine cranberry roots of bogs, within 3 or 4 inches of the surface. On July 28, in the same places, they hardly could be found among the roots, but were abundant 6 to 10 inches below the surface, many being in the peat under the sand. One was 4 inches deep in the peat. On December 3, in the same locations, they were 3 to 5½ inches below the surface, the lowest being near the water table. It seems from this that the insect works deeper into the soil as a bog dries out in summer and comes up again with a rise of the water.

The Army Worm (*Cirphis unipuncta* Haw.).

In previous reports,[1] the fall army worm (*Laphygma frugiperda* S. & A.) and the greasy cutworm (*Agrotis ypsilon* Rott.) were mentioned as harming bogs after removal of the winter flowage in July. In 1919 a destructive visitation of the army worm under like circumstances on a bog at Mays Landing, N. J., was reported, worms of the infestation one-third to one-half grown being brought to the writer on August 8. Moths reared from these worms emerged September 9 and 10. The winter water had been let off from this bog about July 5.

On July 20, 1920, army worms, many nearly mature, were found damaging a bog at Assonet, bared of its winter flowage June 16, and on July 24 they were found abundant on a bog in Carver, bared of its flowage July 2, the largest being one-fifth to one-quarter grown. It is noteworthy, in connection with these infestations, that this pest was prevalent in most of the Mississippi Basin in both 1919 and 1920. The former year it was

[1] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 232; Bul. No. 192, 1919, p. 133.

reported as injuring corn or grass in the following towns in eastern Massachusetts: Wilmington, Canton, Bourne, Falmouth, Barnstable, Brewster and Chatham. That year it destroyed 20 acres of corn on one farm in Bourne. In 1920 it seriously hurt several acres of corn in Bourne.

The army worm and the fall army worm are the two more common of the three harmful insects known to infest the bogs as a result of letting off the winter water in midsummer. The outbreaks of both species nearly always start in the southern States. They are noted there by the Bureau of Entomology which forecasts their spread into the North. Such forecasts were published in both 1919 and 1920. Cranberry growers contemplating holding winter flowage very late should consult the Bureau as to the prospective abundance of these pests. The army worm probably never greatly harms cranberry bogs reasonably free of grasses except in infestations following very late removal of the winter flood.

The Cranberry Fruit Worm (*Mineola vaccinii* Riley).

In 1919 this pest did less harm than in any previous year of the writer's experience. Its reduction was to be expected from the mildness of the previous winter and the wetness of the growing season.[1] The egg parasitism (*Trichogramma*) examined ranged from 16 to 88 per cent on dry bogs, and from 0 to 37 on flowed ones.

In 1920 the insect did much more harm than in 1919, the winter before having been severe. The egg parasitism ranged from 14 to 50 per cent on dry bogs, and from 0 to 25 per cent on flowed ones.

The Black-head Fireworm (*Rhopobota vacciniana* (Pack.)).

This pest was less harmful in 1919 than in any previous year of the writer's experience. The second brood seemed to be entirely suppressed on some bogs; on others it began hatching freely, but for some cause, perhaps disease, as a rule faded out without doing much damage. In 1920 this worm was less harmful than usual, but more so than in 1919.

Results of spraying tests in 1920 support previous experience in indicating that while 1 part of Black-Leaf 40 in 800 parts of water, with 2 pounds of soap to 50 gallons added, is fairly effective in killing the worms, it is probably better economy, all things considered, to use the insecticide at the rate of 1 part to 400 parts of water. One part to 800, with the soap, kills the moths satisfactorily. At either strength the spray is safe to use when the vines are in bloom. Lead arsenate may be used with Black-Leaf 40 if the soap is left out,[2] but it should not be so used unless other pests, such as the gypsy moth or spanworms, are also to be treated, for the soap makes the Black-Leaf 40 more effective.

As cloudiness or dark water, by reducing the light reaching the plants and so lessening photosynthesis, causes a marked decrease of oxygen in the water of a cranberry bog flooding to be maintained, it seems that,

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[1] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 227.

[2] The arsenate and soap make a burning mixture.

under such conditions of light reduction, the forty-eight-hour flooding period hitherto advocated for treating this insect may be much reduced, for the oxygen deficiency should affect the worms as well as the plants.

The Gypsy Moth (*Porthetria dispar* L.).

In 1919 this insect hurt the bogs more than any other. In 1920 it did little harm, as it was generally less prevalent and was treated much more effectively by the growers.

In 1920 Mr. Walter F. Holmes, the gypsy-moth division superintendent for Cape Cod, and the writer tested the open nozzle for treating this pest on the bogs. This is the nozzle used in the gypsy-moth work to spray tall trees from the ground. As tested it proved unsatisfactory for bog spraying, as it was hard to spray at such long range without skipping considerable areas; but it should be tried further, with smaller nozzle holes and lower pressures.

Experience and experiments in recent years have shown that this insect can be controlled readily on the bogs by —

1. *Holding the winter flowage until May 25.* This will kill the eggs laid on the bog the season before, and in most years it also will catch most of the worm wind-drift.

2. *Reflowing about May 29 for thirty-six hours.* The wind-drift is about over then, and the water will kill the worms before they do much harm unless they are unusually numerous. This flooding also will destroy other pests that may be at work, such as the false army worm (*Calocampa*), blossom worm (bud worm) and fireworm. After the gypsy caterpillars are one-third grown, a fourteen-hour flooding kills them, few getting ashore with life enough to eat afterward. They seem to thrash themselves to death in the water, as do apparently all other growing foliage-eating worms of the cranberry, except those that sew the leaves together. If the worms are very numerous, however, it is better not to delay the flooding after the above date in average seasons. The date for the earliest springs is May 24 and for the latest June 3.

3. *Spraying with lead arsenate (3 pounds of powder or 6 pounds of paste to 50 gallons of water) about May 24.* Well applied, this treatment is sure death to the worms when they are small. They are hard to poison when over half grown. In very early springs the spraying should be done about May 18; in very late ones about May 30.

4. *Keeping the maturing worms from getting onto the bogs. This is done best by:* —

(*a*) *Removing the trees, especially the oaks, for some distance back from the bog margin.* The removal of the underbrush (scrub oaks, etc.) also would help, but this seems too costly.

(*b*) *Keeping the marginal ditch cleaned out and partly full of water, and maintaining a film of kerosene or crude oil on the water during the worm-crawl period.*

Bog Management.

Experience and the results of recent experiments lead to the conclusion that winter-flowed bogs not reflowed in June should be sprayed once regularly, a few days before the vines blossom, with this mixture: —

Black-Leaf 40,	1 gallon
Water,	400 gallons
Fish-oil soap,	16 pounds

This treatment largely takes the place of the June reflow in reducing various harmful pests, especially —

1. The black-head fireworm (*Rhopobota vacciniana* (Pack.)).
2. The spittle insect (*Clastoptera vittata* Ball).
3. The girdler (*Crambus hortuellus* Hübner).
4. Leaf hoppers (mainly species of *Euscelis* [1]) and spring-tails (*Collembola*). These forms abound among the vines of bogs not reflowed, and must drain their vitality considerably. Cranberry vines often seem stimulated in growth by nicotine sprays. Probably this is usually due to the reduction of insect drains.

Resanding.

The results with two plots on the station bog that have not been sanded since 1909 are shown in Tables 9 and 10. The check areas in each case bordered different sides of the plot. The berries were Early Black and were picked and stored in 1920 on September 18. They were stored in bushel crates, 6 bushels being used in each case, and were examined November 26 to December 2 by the "seven-sample" method. No distinct effect on keeping quality from resanding was revealed.[2] These plots yielded as well as the surrounding bog until 1916.[3] Table 10 shows how since 1915 their average productiveness has fallen below that of their checks. The last five years these plots have been more thinly vined than the surrounding bog.

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[1] Identified by W. L. McAtee of the Bureau of Biological Survey.

[2] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 219, Table 18; Bul. No. 192, 1919, p. 134, Table 14.

[3] Mass. Agr. Expt. Sta., Bul. No. 168, 1916, p. 27, Table 15.

TABLE 11. — *Sanding Plots in 1920. Effect of Resanding on Keeping Quality of Cranberries.*

Plots and Checks.	Area (Square Rods).	Resanded.	Percentage of Berries showing Decay at End of Storage.
V,	9	Not since 1909,	15.63
V (check 1),	9	Spring of 1912, fall of 1914, spring of 1917 and spring of 1919.	14.85
V (check 2),	6	Spring of 1912, fall of 1914, spring of 1917 and spring of 1919.	13.85
V (check 3),	9	Spring of 1912, fall of 1914, spring of 1917 and spring of 1919.	17.41
O,	9	Not since 1909,	13.61
O (check 1),	6	Fall of 1911, fall of 1914, spring of 1917 and spring of 1919.	18.83
O (check 2),	6	Fall of 1911, fall of 1914, spring of 1917 and spring of 1919.	17.28
O (check 3),	9	Fall of 1911, fall of 1914, spring of 1917 and spring of 1919.	12.86

TABLE 12. — *Productiveness of Sanding Plots V and O from 1916 to 1920, inclusive.*

Plots and Checks.	Resanded.	Yields per Square Rod (Bushels).						
		1916.	1917.	1918.	1919.	1920.	Average, 1916-20.	Average, 1912-15.
V,	Not since 1909,	.93	.60	1.59	.24	1.22	.92	1.250
V (checks),	Four times since 1909,	1.39	.65	2.37	.16	1.41	1.20	1.052
O,	Not since 1909,	.93	.63	1.39	.19	1.07	.84	.864
O (checks),	Four times since 1909,	1.24	.63	1.95	.15	1.19	1.03	.895

Relation of Weather to Cranberry Flooding Injury.

The station bog began the season of 1919 with fair prospects, the vines having a good supply of blossom buds. Partly to check the fireworm and partly as a test treatment of the "rosebloom" disease (*Exobasidium oxycocci*), it was flooded the night of June 16, the water being held about forty-eight hours. A day or two after the water was let off, most of the buds were found to have been killed by it. This was puzzling, as the bog had been flowed with the vines in the same stage of growth in previous years without material harm. Very hot weather had accompanied some of the former June floodings, the water temperature sometimes reaching 86° F. As the first day of this flooding (June 17) was cloudy and the second (the 18th) was not very warm, the injury hardly could have been due to temperature alone.

The writer tried in every way to find the cause of the disaster. The effects of that June's floodings on many other bogs were investigated, and it was found that no notable injury had resulted anywhere except on bogs that had been under water June 17. That day's flooding had done much harm in all the five other cases found. It seemed, therefore, that there was something peculiarly harmful about the weather of the 17th. As that day had been darkly cloudy, comparative experiments in immersing vines in water under shade and in sunshine suggested themselves. Many such tests were made, pieces of cranberry turf with the vines being submerged in some cases in tubs and in other cases in a pond. These tests took place in late June and in July, the first vines being budded and partly in blossom, and the last lots with the bloom gone and bearing small berries. The immersion periods ranged from two to four days. The degree of shade over the shaded lots varied in the different experiments, but in no case did the light seem reduced as much as it is on a real cloudy day. In all these tests the tender parts of the shaded vines were much hurt by the submersion, while the vines immersed without shading were injured little, the contrast between the shaded and unshaded vines in the tests in which the shade was heaviest being striking.

The uniform result of these experiments seems ample proof that the continued reduction of light by cloudiness is harmful to cranberry vines under water during their rapid summer growth. This being so, dark swamp water is more likely to do harm than clear water, for it reduces the light reaching the plants more; also deep flooding must be worse than shallow, for the deeper the water the more light is cut off. These conclusions accord with effects of cranberry flowage commonly observed. Bogs flooded with dark water are oftener hurt than others, and whenever a bog is hurt either by late holding of the winter water or by reflooding, the parts most deeply submerged suffer most.

Dr. H. F. Bergman of the Bureau of Plant Industry determined from time to time the oxygen content of the water used in the immersion experiments in tubs. In his papers on this work lately published,[1] he gives what is probably the true explanation of the harmful effect of shading, by cloudiness or otherwise, in summer cranberry flooding. Apparently the injury is due to drowning of the more rapidly growing parts of the plant, the oxygen in the water being reduced below the respiratory needs of these parts too long.

As Dr. Bergman shows, photosynthesis tends to keep up the oxygen content of a bog flowage. One has only to see the many bubbles of oxygen that form on the leaves of the flooded vines in clear summer weather to appreciate this. As photosynthesis depends on light, cloudiness greatly reduces it or stops it entirely. On the other hand, respiration, the process that uses up oxygen, goes on without regard to light. Apparently for this reason cloudy weather is much more dangerous than clear weather for flooding the bogs in their season of active growth. The days of the June

[1] Ann. Rept. Cape Cod Cranb. Gr. Assoc., 1919–20, pp. 19–30. Amer. Journ. of Bot., 1: 50–58, January, 1921.

floodings are about the longest in the year. In clear weather they allow photosynthesis to go on about fifteen hours of the twenty-four, the oxygen in the water thus being replenished three-fifths of the time.

From what is known about the effect of temperature with other species,[1] a rise of 18° F. must more than double the rate of respiration in the new growth of cranberry. Therefore a combination of very cloudy weather with a high water temperature seems especially dangerous in the flooding of actively growing vines; for, while the stopping of photosynthesis allows the oxygen in the water to become much reduced, the high temperature greatly increases the need of the plants for oxygen. This was the weather combination of June 17. As already stated, the day was darkly cloudy. It was also warm for a cloudy day, the temperature at the station bog reaching 77° F.; also, as the 14th, 15th and 16th had been warm days with warm nights, the water must have become quite warm before it was put on the bog. That warm water is not notably harmful in cranberry flooding in clear weather is explained by the fact that a rise in temperature, with light abundant, increases the rate of photosynthesis almost as much as that of respiration.[2]

Water Injuries to Cranberry Buds.

When, in flooding, cranberry blossom buds are hurt by drowning (lack of oxygen) they usually are either entirely killed, the whole bud turning brown and never opening, or they are injured only on one side, in which case the point of the bud soon bends toward the hurt side, and one or two lobes of the corolla commonly turn brown. When but one side of the bud is hurt it usually opens to form an imperfect blossom, but rarely develops a berry.[3] When this drowning injury occurs it is severest in the deepest water and on the sides of the ditches.

Another bud injury was observed in 1919 in connection with the flooding of three bogs located near together. The berries on these bogs are Early Black, and the water for flooding them all has the same source. All three bogs were flooded before sunrise June 12. The water was let off the two lower ones on the night of June 13, the flooding having lasted about forty-two hours and both days having been clear. The night of June 13 was cold, the temperature at near-by bogs falling to 33° F. The water on the upper bog was held until the night of June 14, the flooding period being about seventy-two hours.

These bogs were examined a few days later. Most of the buds on the two lower ones showed a peculiar injury, their tips having turned dark red or blackish and having opened somewhat. In this condition they had

[1] Van't Hoff: Studies in Chemical Dynamics, trans. by Ewan, 1896, p. 126. Kuijper: Rec. Trav. Bot. Néerl., 7: 131–239, 1910. Gore: U. S. Dept. Agr., Bur. of Chem., Bul. No. 142, 1911, pp. 5–28.

[2] Matthaei; Phil. Trans. Roy. Soc., B, 197: 47–105, 1905.

[3] As might be expected, for the pistil respires faster than any other part of the flower. Maige: Ann. Sci. Nat., Bot., Ser. 9, 14: 1–62, 1911.

a distinctive appearance, with none of the marks of drowning injury. Many of the buds on the upper bog (where the water was held for seventy-two hours) showed drowning injury, but none looked like those hurt on the other bogs. These bogs were examined again late in August, and the lower ones (where the water was held forty-two hours) had little fruit, the crop being plentiful only in low places and along the ditches. On the other bog the crop was heaviest on the high parts.

The buds on the lower bogs may have been hurt by exposure to the cold when the water was let off, though no frost was seen in the vicinity that night. The fact that the buds were hurt less in the low places, as evinced by the heavier fruiting there, shows that the water tended to prevent the injury.

Blueberry Work.

To control the gypsy moth, different parts of the blueberry plantation were sprayed on June 3, 1919, with these mixtures: —

1. Three pounds of lead arsenate powder to 50 gallons of water.
2. Three pounds of lead arsenate powder and 2 pounds of Good's Caustic Potash Fish-oil Soap No. 3 to 50 gallons of water.

Both sprays killed the worms, but the one with soap burned the foliage and blossom buds badly.

No budding was done in 1919 because of a lack of good sprouts to bud into, but in 1920 it was done as follows: —

Pioneer (620A) variety, 82 buds.
Cabot (834A) variety, 208 buds.

Gypsy-moth caterpillars showed a special fondness for the growth from inserted buds, giving so much trouble that it seemed impossible to continue the work, until it was found that the caterpillars were stopped by tree tanglefoot around the bases of the sprouts.

Sixty-eight small Pioneer plants from the Bureau of Plant Industry were added to the station planting, 2 in 1919 and 66 in the spring of 1920.

The drainage of the plantation was improved by new construction in 1920.

The plantation produced 98 quarts of berries in 1919, and 147 in 1920, the bearing area being about a quarter of an acre. The fruit was sold locally at moderate prices. Most of the bearing plants are untested seedlings (four years old in 1920) provided by the Bureau of Plant Industry. A few of these seem promising, — one in 1919 yielding over 2 quarts of berries which averaged about 15 mm. in diameter, the largest measuring 18 mm. The largest berries from the plantation in 1920 were 20 mm. (about eight-tenths of an inch) through.

The proper development of the blueberry work and of the cranberry variety work requires several additional acres of rough land, and an early appropriation should be made for it.

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